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PREDICTING RATE OF FIRE SPREAD (ROS) IN ARIZONA OAK CHAPARRAL: Field Workbook



**USDA Forest Service
General Technical Report RM-24**

May 1976

**Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521**

Abstract

Davis, James R., and John H. Dieterich.

1976. Predicting rate of fire spread (ROS) in Arizona oak chaparral: Field workbook. USDA For. Serv. Gen. Tech. Rep. RM-24, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

To facilitate field use of the rate of fire spread equation used in Arizona oak chaparral, step-by-step instructions are presented in workbook form. Input data can be either measured or estimated from the tables and figures included; a sample computation form may be duplicated for field use. Solving the equation gives the land manager the guidelines for planning fire control efforts, or for using prescribed fire in the brush type.

Keywords: Rate of fire spread, prescribed fire, oak chaparral.

General Technical Report RM-24

May 1976

PREDICTING RATE OF FIRE SPREAD (ROS) IN ARIZONA OAK CHAPARRAL: Field Workbook

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¹Forester and Principal Forester, respectively, in the Station's Fire Management Research Work Unit. Davis is assigned to Fort Collins; Dieterich is at Tempe, in cooperation with Arizona State University. Station's central headquarters is maintained at Fort Collins, in cooperation with Colorado State University.

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Introduction

Predicting fire behavior is a difficult task. Long-distance spotting, development of fire whirls, and simultaneous ignition over large areas are fire behavior characteristics that are difficult to forecast with accuracy, and can be predicted only in a very general way. It is important, however, that the fire manager be able to predict rate-of-fire spread (ROS) in order to manage all types of fire more effectively. Research Paper RM-101 "Predicting fire spread in Arizona's oak chaparral" by Lindenmuth and Davis (1973) presents the results of research designed to provide improved estimates of rate-of-fire spread in the Arizona oak chaparral. It describes the predictive fire spread model in detail, but is not intended to be a manual for use in the field.

The purpose of this field workbook is to put these research findings into a form that can be more readily utilized by the fire manager. The model, or formula, in this workbook can be used for predicting ROS on wildfires; it has an equally important role in predicting ROS for prescribed burning. The model was developed by burning a number of experimental fires, and has been tested on a number of wildfires. For user convenience, the ROS formula is set up in a worksheet form (see inside back cover). Thus the user determines certain values in the field, records them on the worksheet, and (after appropriate transformations) calculates the predicted ROS.

It is not always easy to verify ROS predictions in the field; thus the ROS figures must be considered as *indicators* or *guides*—just as the Burning Index or Fire Load Index are considered as guides in predicting burning conditions or manpower requirements. Even with these guides, considerable judgment is needed in applying the predicted values. In spite of these uncertainties, however, the fire manager *should* be able to relate the predicted ROS to the fire behavior he observes on the fire. Knowing the ROS value, and tempering this information with experience gained in watching fires burn, the fire manager can fairly accurately relate fire spread to the predicted value, and thereby control and apply fire more safely and effectively.

Ground Rules

The following qualifying statements are presented to help clarify some of the basic assumptions that were considered, or omitted, in developing the predictive model. These statements do not necessarily detract from the accuracy of the model—they indicate the model must be used with a certain amount of good judgment.

- Litter or dead twigs $\frac{1}{4}$ inch or less in diameter must be reasonably dry (15 percent moisture content or less) for reliable predictions. Usually this will be reached with 5 consecutive days of seasonably warm weather, April through October, and with 10 days during the rest of the year.
- Winter rainfall records representative of the area for which the ROS values are desired (past wildfires, going wildfires, or prescribed burns) must be available. These records make it possible to select one of the three following climatological conditions that best describe past winter rainfall:

Condition 1— ≥ 3.00 inches of precipitation preceding December + January.

Condition 2— < 3.00 inches of precipitation preceding December + January. Precipitation February + March < 3.00 inches.

Condition 3— < 3.00 inches of precipitation preceding December + January. Precipitation February + March ≥ 3.00 inches.

- The burning experiments on which the model was based were conducted in pure shrub live oak (*Quercus turbinella* Greene), and oak leaves were used for determining leaf moisture content.
- Slope was *not* included as a factor in the model because the experimental burns were conducted on essentially flat terrain. (Obviously the fire manager would not ignore slope as a factor in predicting ROS; because the interactions of slope and wind with fuel are complex, he will have to use his best judgment in "accounting" for slope as he attempts to interpret the meaning of his predicted ROS value.)
- Rate of Spread is expressed in terms of feet per minute—forward spread with the wind, or radial spread with no wind.

What You Need—How You Get It

An almost unlimited number of variables or factors could be measured or considered in developing a model to predict ROS. Most of these variables fall in one of the following categories: climatological data (past weather records), current weather factors, or fuel characteristics (chemistry, loading, and moisture). The variables selected—those that you will need to plug into the formula—are described below.

Leaf moisture content (percent).—Expressed in terms of oven-dry weight, this variable can be measured directly if you have the proper facilities, *or*, more conveniently, leaf moisture content can be estimated from *table 1*.

Air temperature (°F).—Easily measured. The dry bulb on a sling psychrometer will do. The observed value is not used directly in the formula, however; *table 2* is used to transform the actual temperature to the value to be entered in the formula. Measure on site if possible.

Relative humidity (percent).—May be accurately measured with a sling or fan psychrometer. Measure on site if possible. *Table 3* must be used to get a converted value for use in the ROS equation. For reconstructing ROS on *past fires*, humidities (and temperatures) could be read from an accurately adjusted hygrothermograph.

Net solar radiation (langley/minute).—Can be measured directly with appropriate instrument, but a very good estimate may be made from *figure 1*.

On a *clear* day, use your judgment to select a value between the maximum and minimum values; on cloudy days, use cloudy day curve.

Figure 1 shows midday values. For time before and after midday, correct by multiplying the selected value from *figure 1* by the factor found in *table 4*. With this value, go to *table 5* to get the transformed radiation value.

Windspeed (miles/hour).—Easily measured with hand-held or tower-mounted wind instruments. Adhere to standard 20-foot-high anemometer exposure if possible. Record directly. Measure on site if possible.

Chemical coefficient.—This variable accounts for the phosphorus content of the leaves which affects their flammability. Use *table 6* to determine the value to be entered in the formula.

A "computation worksheet" with sample calculations (see fig. 2) is provided in the "How To Use It" section that shows input variables *measured*, needed *transformations*, standard *coefficients*, and equation *terms*. A blank form that may be reproduced for field use appears on the inside back cover.

How To Use It

Once the measured and transformed values are entered on the worksheet and the mathematical coefficient is applied to yield the equation term, it is a relatively simple task to determine the ROS. The ROS equation, a sample problem, and the steps for solving it, are listed below. The equation shows the *constant values* and *variables* that are measured or determined from tables. The sample problem is worked out by following the appropriate steps on a worksheet (fig. 2).

Table 1.--Leaf moisture content (M) values for approximating ROS under three conditions

Month	Condition			Definition
	1	2	3	
	<i>Percent</i>			
March	79	79	79	<u>Condition 1:</u> >3.00 inches of precipitation preceding December + January.
April	82	76	81	
May	134	74	82	
June	96	73	89	<u>Condition 2:</u> <3.00 inches of precipitation preceding December + January.
July	86	70	79	
August	86	105	93	
September	81	99	88	<u>Precipitation February + March</u> <3.00 inches.
October	80	89	84	
November	81	88	81	
December	81	86	81	<u>Condition 3:</u> <3.00 inches of precipitation preceding December + January.
January	77	85	77	
February	78	84	78	

Table 2.--Transformation of air temperatures

Measured air tem- perature	0	1	2	3	4	5	6 ↓	7	8	9
4	20.0	20.8	21.5	22.0	22.8	23.4	24.5	25.5	26.5	27.7
5	28.5	30.0	31.5	33.0	34.5	36.0	38.0	39.5	41.5	43.5
6	46.0	48.5	51.3	54.0	57.0	61.0	65.7	70.3	74.5	78.8
7	83.0	86.3	89.5	91.5	93.0	94.5	95.5	96.5	97.0	97.5
8 →	98.0	98.2	98.4	98.6	98.8	99.0	99.0	99.0	99.1	99.1
9	99.1	99.2	99.2	99.3	99.4	99.5	99.5	99.6	99.7	99.7
10	99.8	99.8	99.8	99.9	99.9	99.9	99.9	99.9	100.0	100.0
11	100.0									

Example: $86^{\circ} = 99.0$ transformed

Table 3.--Transformation of relative humidity

Measured relative humidity	0 ↓	1	2	3	4	5	6	7	8	9
0					4.5	4.6	4.7	4.8	5.0	5.1
1	5.5	6.0	6.5	7.5	8.7	10.2	11.8	13.5	15.5	18.0
2 →	20.5	23.0	25.2	28.0	30.0	32.0	34.0	36.0	37.8	39.5
3	40.5	41.5	42.5	43.5	44.2	45.0	45.6	46.2	47.0	47.5
4	48.0	48.4	48.8	49.2	49.6	50.0	50.5	50.9	51.3	51.7
5	52.0	52.2	52.4	52.6	52.8	53.0	53.2	53.5	53.7	53.9
6	54.0	54.1	54.2	54.3	54.4	54.5	54.6	54.7	54.8	54.9
7	55.0									

Example: 20% = 20.5 transformed

Table 4.--Net solar radiation correction for time of day

Month	Time of day								
	8	9	10	11	12	13	14	15	16
Apr.- Sept.	0.31	0.48	0.76	0.93	0.98	1.00	0.94	0.83	0.32
Oct.- Mar.	.00	.25	.64	.89	.99	.99	.79	.47	.00



Figure 1.—Midday radiation values. Near sources of significant pollution, net radiation would be lower. The aberrations in the May-June period apparently result from atmospheric haze associated with drought and turbulence.

Table 5.--Transformation of solar radiation

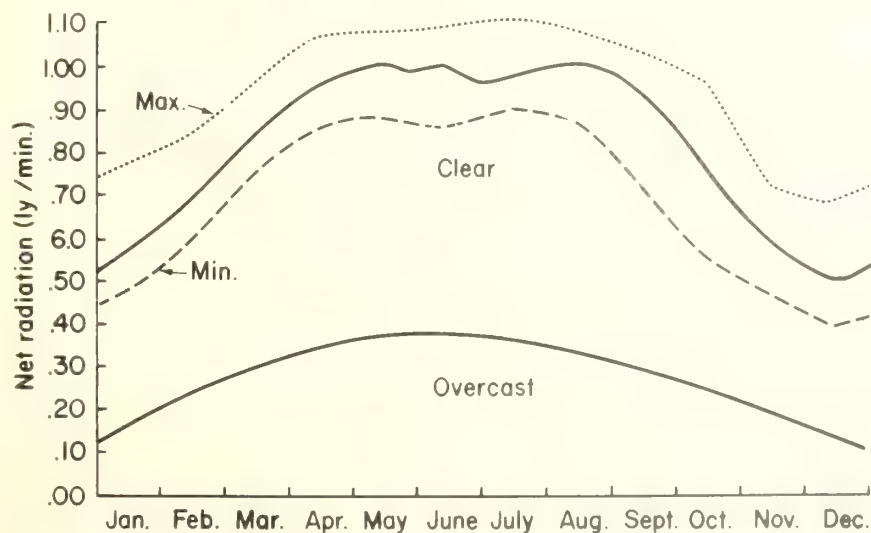
Measured net solar radiation	0	1	2	3	4	5	6	7	8	9
								↓		
.2									.150	.170
.3	.185	.205	.220	.240	.255	.270	.290	.310	.325	.340
.4	.355	.370	.388	.404	.415	.431	.488	.464	.480	.495
.5	.510	.525	.540	.553	.566	.580	.595	.609	.623	.636
.6	.650	.663	.679	.693	.707	.720	.733	.745	.757	.768
.7	.780	.790	.800	.810	.820	.830	.839	.848	.856	.865
.8	.873	.881	.888	.896	.904	.910	.915	.920	.926	.932
.9	.936	.940	.943	.945	.948	.950	.952	.954	.956	.958
1.0 →	.960	.960	.960	.960	.960	.960	.960	.960	.960	.960
1.1	.960									

Example: 1.07 = .96 transformed

Table 6.--Chemical coefficient to correct for foliar phosphorus content under three conditions¹

Month	Condition			Month	Condition		
	1	2	3		1	2	3
	<i>Percent</i>				<i>Percent</i>		
March	1.0	2.2	2.2	August	1.7	1.0	1.0
April	1.0	1.6	1.6 (early)	September	1.0	1.0	1.0
			1.0 (late)	October	1.0	1.0	1.0
May	1.0	1.6	1.0 (early)	November	1.0	1.0	1.0
			1.6 (late)	December	1.0	1.0	1.0
June	1.0	1.7	1.7	January	1.0	1.7	1.7
July	1.6	1.6	1.0	February	1.0	1.8	1.8

¹Conditions as defined in table 1.



The Equation

$$\text{ROS (ft/min)} = (10.0 - 0.040 M + 0.059 T - 0.121 H \\ + 6.48 r + 0.301 W) \text{ CC}$$

where

M = leaf moisture content (%)

T = air temperature (°F)

H = relative humidity (%)

r = net solar radiation (ly/min)

W = windspeed (m/h)

CC = chemical coefficient

Sample Problem

Assume: Condition 1, 1300 hours, clear, August weather. These criteria indicate a Leaf Moisture Content (M) of 86%. The air temperature (T) is measured as 86°F; relative humidity (H) as 20 percent; and windspeed (W) as 4 miles per hour. Net solar radiation (r), as determined from the "maximum" curve in figure 1, is 1.07 ly/min. Chemical coefficient (CC) from table 6 is 1.7.

Steps for Solving the Equation

Step 1.—Enter the estimated or measured input variables on the worksheet.

Step 2.—List the transformed numbers from tables 1 through 6 and figure 1 alongside the estimated or measured column from step 1.

Step 3.—Multiply the numbers in step 1 (or step 2 if transformed) by appropriate *coefficient* from the equation.

Step 4.—Add the terms computed in step 3, keeping signs straight. (*Don't forget to add the constant term, 10.0*).

Step 5.—Multiply answer from step 4 by chemical coefficient to get estimated ROS.

The *estimated or measured values, transformed values, standard coefficients, and equation terms* are shown on the sample worksheet. The predicted ROS value of 29.48 (rounded off to 29), is your final answer *based on the formula*. As mentioned earlier, this value must be tempered with *judgment and experience* when predicting the behavior of a wildfire or a planned prescribed fire.

What It Means

Predictions with this ROS model were compared with actual ROS on four small evaluation fires. Spread was measured both within clumps and between a number of clumps across breaks of varying widths. This small sample indicates that fires in broken, discontinuous fuel spread about 5 percent slower, on an average, than fires in continuous, relatively homogeneous fuel.

How can statistical ROS predictions be interpreted by the fire manager?—Key ROS numbers are 10, 20, and 40 for *level* or *slightly sloping* areas.

Location: Mingus
 Date: 8/10/75
 Hour: 1300

Rate of Spread
 Computation Worksheet

Line	Input variables		Standard coefficients	Equation term
		Estimated or measured	Transformed	
1.	Constant			+ 10.0
2.	Leaf moisture content, M (%) (table 1)	86	—	x (-0.040) = - 3.44
3.	Air temperature, T (°F) (table 2)	86	99	x (+ 0.059) = + 5.84
4.	Relative humidity, H (%) (table 3)	20	20.5	x (-0.121) = - 2.48
5.	Net solar radiation, r (ly/min) (fig. 1)	1.07	—	
6.	Time-of-day correction (table 4)	1.00	—	
7.	Line 5 x line 6 = (. . . and table 5)	1.07	.96	x (+ 6.48) = + 6.22
8.	Windspeed (m/h)	4	—	x (+ 0.301) = + 1.20
9.	Total			17.34
10.	Chemical coefficient (table 6)	—	1.7	
11.	ROS (ft/min) (line 9 x line 10) =			29.48

Figure 2.—Sample calculations on computation worksheet, showing the input variables, transformations, standard coefficients, and equation terms used to determine rate of spread (ROS).

When predicted ROS is less than 10 (approximately), fire probably will not spread well. Fire set repeatedly may spread through the litter and consume some aerial fuels, but normally will not crown continuously through an individual clump or spread from clump to clump.

Between 10 and 20 (approximately), individually ignited clumps probably will burn reasonably well, but fire normally will not spread from clump to clump continuously.

Above 20, fire normally will spread from clump to clump continuously, and up to 40 will burn steadily, but not explosively.

Above 40 (approximately), fires will probably burn intensely, spread rapidly, and conditions will probably be too severe for most prescribed burning.

General.—People experienced with fire characteristics in Arizona oak chaparral have always maintained that chaparral either burns fiercely or does not burn at all—no graduation in between. This rule of thumb is relatively accurate. The critical ROS threshold is around 20 feet per minute; conditions must be suitable for generating spread at or above that rate before fire will spread across country. Thus the minimum sustained spread (without spotting) ever seen, usually in intentional fire, is about one-quarter mile per hour; in wildfires, normally one-half mile per hour or higher because wildfires tend to occur during some of the worst conditions and commonly include spotting.

A 28,400-acre wildfire on the Prescott National Forest, May 14-20, 1972, provided an operational check of the statistical model and interpretations. The initial ROS, from 1215 to 1500 hours in a mixture of oak and manzanita chaparral, was scaled at 45 feet per minute, 1.25 feet per minute less than the fastest spreading research fire. The wildfire included some short-range spotting and a variety of slopes and fuel conditions. Predicted ROS was 40 feet per minute (based on data from the tables, and measured temperature, relative humidity, and wind). This small difference (45 vs. 40 feet per minute) probably is attributable to spotting, favorable slope-wind interaction during part of the run, and the admixture of manzanita.

The type of fire that does not spread from clump to clump is potentially quite useful in land management. It can be used to burn firebreaks and small areas safely without bulldozing, brush smashing, or other special measures heretofore employed in intentional burning, at considerable cost both in dollars and site disturbance. Forming fuelbreaks by nonspreading fire is feasible, economical, and effective, although additional research is needed to work out operational details. When designed to dissect large areas of chaparral, these breaks can substantially lessen the probability of large, catastrophic wildfires.

Davis, James R., and John H. Dieterich.

1976. Predicting rate of fire spread (ROS) in Arizona oak chaparral: Field workbook. USDA For. Serv. Gen. Tech. Rep. RM-24, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

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Keywords: Rate of fire spread, prescribed fire, oak chaparral.

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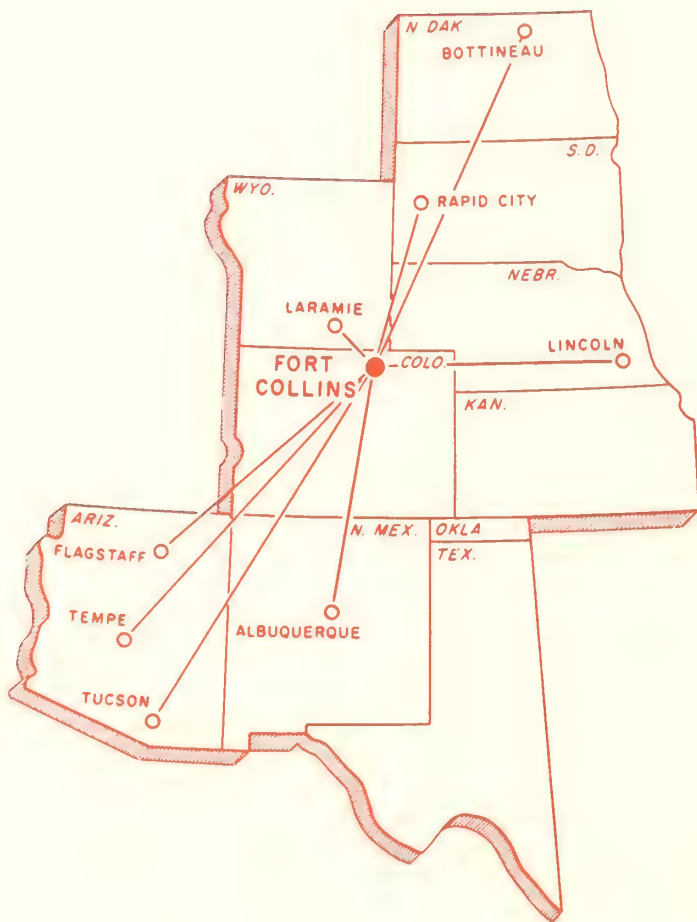


Location: _____
Date: _____
Hour: _____

Rate of Spread
Computation Worksheet

Line	Input variables			Standard coefficients	Equation term
		Estimated or measured	Transformed		
1.	Constant				+ 10.0
2.	Leaf moisture content, M (%) (table 1)		—	x (-0.040)	= -
3.	Air temperature, T (°F) (table 2)			x (+ 0.059)	= +
4.	Relative humidity, H (%) (table 3)			x (-0.121)	= -
5.	Net solar radiation, r (ly/min) (fig. 1)		—		
6.	Time-of-day correction (table 4)		—		
7.	Line 5 x line 6 = (. . . and table 5)			x (+ 6.48)	= +
8.	Windspeed (m/h)		—	x (+ 0.301)	= +
9.	Total				
10.	Chemical coefficient (table 6)	—			
11.	ROS (ft/min) (line 9 x line 10) =				

(may be reproduced for field use)



May 1976

Measuring Scenic Beauty: A Selected Annotated Bibliography

USDA Forest Service
General Technical Report RM-25
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Arthur, Louise M., and Ron S. Boster.

1976. Measuring scenic beauty: A selected annotated bibliography.
USDA For. Serv. Gen. Tech. Rep. RM-25, 34 p. Rocky Mt.
For. and Range Exp. Stn., Fort Collins, Colo. 80521

Of the 167 papers covered, 95 percent date from 1965. Citations are divided into four categories: literature reviews, inventory methods, public involvement, and miscellaneous. Many annotations also carry a "critical comment."

Keywords: Esthetics, land use planning, landscape management, inventory.

Measuring Scenic Beauty: A Selected Annotated Bibliography

Louise M. Arthur, Economist, and Ron S. Boster, Principal Economist
Rocky Mountain Forest and Range Experiment Station¹

¹Research supported here was conducted while authors were located at the Station's Research Work Unit at Tucson, in cooperation with the University of Arizona. Station's central headquarters is maintained at Fort Collins, in cooperation with Colorado State University. Arthur is now with the USDA Economic Research Service, Tucson; Boster is with the Division of Program Plans, USDI Fish and Wildlife Service, Washington, D. C.

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Measuring Scenic Beauty: A Selected Annotated Bibliography

INTRODUCTION

Of the 167 papers in this bibliography, 95% date from 1965. Why the sudden interest in measuring scenic beauty? The primary reason seems to center around environmental concerns. Recognition of the need for better integration of environmental concerns with the more easily measured wildland resources and products has resulted in important legislation such as the National Environmental Protection Act, and has surely been a prime factor in the proliferation of scenic beauty assessment techniques. The esthetic consequences of public land management decisions are often the most immediate and noticeable. Yet, public land planners have been at a loss to effectively incorporate the scenic resource into their planning and decision-making processes.

There are several reasons for a bibliography on approaches to scenic assessment. One pertains primarily to researchers in the area; a useful annotated bibliography can be a godsend to a researcher beginning an investigation. Not only can valuable time be saved in searching for citations (known and unknown), but annotations can often tell the researchers enough about a particular article to determine whether a library search or reading is warranted. Critical appraisals provide additional information.

Another reason applies primarily to users of scenic beauty evaluation techniques. There is probably no limit to the number of approaches that can be taken to quantify and/or assess something as elusive as scenic beauty. An annotated bibliography can focus and organize numerous ideas on the subject. Readers can learn what methods are available in order to decide if a new approach must be invented, an existing approach modified, or a previously tested method applied.

Still another reason for a bibliography of this topic stems from our observation of a general lack of attention to published criticism of available approaches. Library research to determine what thinking has already been done is often blatantly overlooked. Hopefully, this bibliography will make the general task of literature review easier.

Finally, this bibliography is needed because so much writing and thinking has been done so recently, and because earlier bibliographies generally have not been confined to techniques and are not always easily available.

In view of the above, this bibliography has the following objectives:

1. To survey and list the literature pertaining to the evaluation of scenic beauty, particularly the scenic beauty of wildlands.
2. To briefly summarize, by way of abstracts, the salient features of various publications.
3. To comment critically on selected references.

Following this introduction are annotated citations of many published works dealing primarily with procedures for assessing, quantifying, or otherwise measuring scenic beauty. The citations are divided into four categories: Literature Reviews, Inventory Methods, Public Involvement, and Miscellaneous. The last category contains procedures for measuring or assessing scenic beauty that either do not fit in any of the other categories or are borderline between one or more categories. We assumed from the start that universal agreement as to which paper belongs in which category (or if a paper actually offered a measurement technique) would be impossible. Many familiar works have been excluded because we felt they did not present a technique.

Most of the annotations are our own. If not, quotation marks show they are taken from the original paper's abstract or summary. In some cases we combined our own words with those of the author. Included with some of the citations is a *listing of headings* or chapters where we felt such a listing would provide useful information. Following most annotations, we have listed the number of references cited.

Many of the annotations carry a "critical comment." For the most part, these comments are our own. Not all such comments are negative, and the absence of critical comments does not necessarily imply we were favorably impressed. We simply critiqued those papers we felt needed comment.

An *author index* is included to assist readers in finding papers by a particular author. The index should reduce problems caused by our often arbitrary inclusion of a paper in one category instead of another.

We hope that this bibliography provides a good overview of available scenic assessment techniques. Because of the intense work in this area, it will probably be somewhat dated as soon as it is published. We hope, however, that it will help other researchers in the exhaustive task of keeping up with the literature in a rapidly developing field.

LITERATURE REVIEWS

This section contains citations, annotations, and critical comments on published works that purport to survey literature related to scenic assessment.

The Aerospace Corp.

[n.d.] Method of scenic alternatives impact by computer: concepts and prospects. 35 p. The Aerospace Corp., El Segundo, Calif.

Abstract

Provides an extensive list and examples of present and potential techniques for portraying landscapes for visual impact analysis. Includes several types of photography, scale models, mapping, drawing, holography, and computer methods. No refs.

Critical Comments

This is simply a listing and does not provide an evaluation of successes or failures of the various methods.

Cerny, James W.

1972. Landscapes amenity assessment bibliography. Exch. Bibliogr. 287. 8 p. Counc. Plann. Libr., Monticello, Ill.

Abstract

A brief overview of the methodologies and purposes of some selected attempts to assess landscape quality. 45 refs.

Coomber, Nicholas H., and Asit K. Biswas.

1973. Evaluation of environmental intangibles. 77 p. Geneva Press, Bronxville, N. Y.

Abstract

A selected review of quantitative techniques dealing with the evaluation of the intangible benefits and costs of the physical environment. The evaluation techniques are separated into monetary and non-monetary models, with the latter category including esthetic measurement models and attractiveness models. The merits and disadvantages of each type of approach are discussed. 321 refs.

Critical Comments

The authors submit that attractiveness models are preferable, because "the physical effort involved in visiting a recreation site represents a more positive response to attractiveness than a merely stated appreciation of such qualities." However, variables other than "attractiveness" and/or esthetic preference may predominate in determining actual use of a site.

Headings

Techniques for the monetary evaluation of environmental intangibles; The use of demand curves; Methods of Evaluation based on willingness to pay; Methods based on 'Alternatives'; Methods based on Expenses; Techniques including secondary benefits; Non-Monetary evaluation of the physical environment; The problem of esthetic measure; esthetic measure techniques; Some problems of esthetic measure models; Attractiveness models; The problem of measurement; Some conclusions.

Craik, Kenneth H.

1971. The assessment of places. In *Advances in psychological assessment*. p. 40-62. P. McReynolds, ed. Sci. and Behav. Books, Palo Alto, Calif.

Abstract

Relates personality research to environmental research and discusses some approaches to assessing environments. 129 refs.

Headings

Assessing the physical and spatial properties of places; Assessing the organization of material artifacts in place; Assessing the traits of places; Person perception versus personality assessment; Trait attributions versus trait designations; Selection of observers for assessment projects; Media of presentation; Nature and format of judgments; Adjective procedures; Rating procedures; Other promising techniques; Assessing the behavioral attributes of places; Assessing institutional attributes of places; The value of comprehensive environmental assessments.

Craik, Kenneth H.

1972. Psychological factors in landscape appraisal. *Environ. and Behav.* 4:255-266.

Abstract

Reviews various studies from 1965-1970 that focus on landscape appraisal and esthetics. 44 refs.

Critical Comments

Coughlin and Goldstein (1970, see p. 14) have shown there is more agreement among people making esthetic judgments than preference judgments, indicating that esthetics is only one of several relevant preferences. Craik's good review and criticism make a similar point; unlike quality, preference may be strongly related to "use." The author's point that individual preferences for landscapes should first be separated from the esthetics of landscapes before quantifying the landscape's inherent value is well taken in that context.

Draper, Dianne

1973. Public participation in environmental decision-making. Exch. Bibliogr. 396, 28 p. Counc. Plann. Libr., Monticello, Ill.

Abstract

An extensive listing of sources under the categories of environmental concerns (89), planning and public participation (54), and voluntary interest group studies (interest groups in general (68), environmental interest groups (42), government and environmental quality (89)). Many of the papers are discussions of the subjects rather than methodologies. 342 refs.

Dunn, Michael C.

1974. Landscape evaluation techniques: An appraisal and review of the literature. Work. Pap. Number 4, 68 p. Cent. for Urban and Reg. Stud., Univ. Birm., Birm., England.

Abstract

"This paper attempts to introduce the various techniques for landscape evaluation, to make an assessment of their utility, and to prepare a framework within which experimental work aimed at identifying techniques or more general usefulness can take place." 116 refs.

Headings

The early development of landscape evaluation techniques; Recent development of the measurement techniques; Landscape preference: Relevance and application; The consensus approach: Synthesis or full circle?; A summary of approaches & problems.

Fabos, Julius Gy.

1971. An analysis of environmental quality ranking systems. Recreation Symp. Proc., p. 40-55. U.S. Dep. Agric. For. Serv., Northeast. For. Exp. Stn., Upper Darby, Pa.

Abstract

A review and analysis of the quantitative ranking systems developed during the past decade for measuring environmental quality. The quality ranking systems are divided into three groups: systems to evaluate resources for policy planning, systems to evaluate resources for the purpose of planning and action on interstate, state, and subregional scales, and systems which evaluate the landscape for a single use (e.g., camping or boating). Each quality ranking system is summarized. At the end of each category the environmental ranking procedures within that category are compared with eight criteria which the author has identified as desirable characteristics and outcomes of utilizing an environmental quality ranking technique. The value of ranking systems and problems which have been part of the present development are also discussed. The author calls for people in different disciplines to combine their knowledge and training to extend the comprehensiveness, accuracy, reliability, and universality of ranking systems. 44 refs.

Critical Comments

A good review and discussion.

Fabos, Julius Gy.

1974. Putting numbers on qualities: The rising landscape assessors. Landscape Archit. 64(3):164-165.

Abstract

Review and critique of some methods of landscape analysis, especially those submitted by Iverson, Plattner, Murray, Polakowski, Riote, Fabos, and Smandon. No refs.

Critical Comments

Published references of these models were not included.

Harrison, James D.

1974. The perception and cognition of environment. Exch. Bibliogr. 516. 79 p. Counc. Plann. Libr., Monticello, Ill.

Abstract

Very extensive, broad-ranged bibliography. Measurement and scaling section is a short presentation of general methods. Sections I-VII are annotated. 690 refs.

Headings

Personality and perception: psychological and philosophical views (13); Attitude formation (48); Environmental sensitivity and selection (44); Environmental effects and behavioral manipulation (7); Strategies for change (13); Measurement and scaling (20); Reviews and collections (13); Other materials (532).

Kaplan, Rachael.

1975. Some methods and strategies in the prediction of preference. In Landscape assessment: Values, perceptions, and resources. p. 118-129. E. H. Zube, J. G. Fabos, and R. O. Brush, eds. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa.

Abstract

A review and criticism of some research in landscape assessment. The advantages of visual (vs. verbal) presentation modes

and public (vs. professional) samples of respondents are discussed. 32 refs.

Kates, R. W.

1970. Human perception of the environment. Soc. Sci. J. 22:648-660.

Abstract

"The purpose of this article is to convey some of the diversity of human perceptions of the environment, to draw on specific studies in an attempt to clarify how human beings in different social and cultural settings perceive the environment and react to it. For this purpose, I have selected four research themes from the body of literature: the use of illusion to infer the reality of visual perception, the quest for the image of the city, the interplay of environmental attitudes and landscapes, and the adjustment of drought as environmental behavior." 36 refs.

Critical Comments

Section on landscape perception is extremely short and general.

Ottar, Tom.

1974. Kenneth Craik's environmental psychology: An overview and bibliography. Exch. Bibliogr. 677. 28 p. Counc. Plann. Libr., Monticello, Ill.

Abstract

"Methodological influences from psychology and philosophy are traced and Craik's method of using these to structure the field of environmental psychology is outlined. His three subsequent research paradigms [models] based on person perception research are described in some detail, listing relevant methodology, citing examples, and making clear his terminology. Attempts are made to establish connections with other relevant fields of study like geography, clinical psychology, i.e. personality assessment, and human ecology, and with specific approaches to environmental psychology like those employed by the ecological psychologists; the aim of this paper being to convey Craik's views of a field of study in which his participation has not gone unnoticed. The paper is concluded by a short critical note." 36 refs.

Redding, Martin J.

1973. Aesthetics in environmental planning. Socioeconomic Environ. Stud. Ser. 187 p. U.S. Environ. Prot. Agency, Washington, D.C.

Abstract

"This report addresses the relationship of aesthetics to environmental planning. The primary emphasis of the research is on the man-environment interaction, with the ultimate goal directed toward improving the understanding of aesthetic concepts and the implication of using those concepts in research and planning activities. The historical development of the Western concept of aesthetics is explored with the aim of showing the relation of the concept to the particular set of attitudes at each period, to illuminate the way in which present concepts relate to today's world. Three primary aspects of the aesthetic concept are discussed; these include aesthetics and the human senses, aesthetics as thinking about the arts, and aesthetics as the science of beauty. Additional factors underlying the concept of aesthetics include: nature as an underlying force; cultural, social and economic phenomena as determiners of aesthetic expression; and aesthetics of American city life. Aesthetics is also discussed in the context of the National Environmental Policy Act.

Methodologies for measuring or quantifying aesthetics are reviewed, as well as a review of the state of the art of research in basic theory for understanding the unquantifiable. A similar

review of selected planning agencies' guidelines and procedures for integrating aesthetics into the planning process is followed with an outline of suggested future research needs." 216 refs.

Critical Comments

Coverage of the topic is broad and the report is thorough, well organized, and well written.

Saarinen, T. R.

1969. Perception of environment. Comm. Coll. Geogr., Resour. Pap. Number 5. 26 p. Assoc. of Am. Geogr., Wash. D.C.

Abstract

Review of research by social scientists on man's perception of and effect on the environment. Paper is organized to cover topics from perception of small scale to large scale spaces. 7 refs.

Headings

Characteristics of the field; Perception studies organized according to scale; Personal space and room geography; Perception of architectural space; Neighborhoods or districts; Paths and roads; The city; Larger conceptual regions; The country; The world.

Shafer, Elwood L., Jr.

1967. Forest aesthetics — a focal point in multiple-use management and research. 14th IUFRO Congr. Pap. 7, Sect. 26, p. 47-71. [Munich, Ger., Sept. 4-9, 1967.]

Abstract

Presents a sampling of the many innovations that managers and researchers are applying to the problems of integrating timber production and forest esthetics. Past research is reviewed and potential research proposed. The author also presents findings of a survey of managers' estimates of the number of years required for various forests to completely recover from various treatments. 32 refs.

U.S. Senate, Committee on Interior and Insular Affairs.

1973. National environmental policy Act of 1969. Environmental indices status of development pursuant to sections 102(B) and 204 of the Act. 46 p. Environ. Policy Div., Congr. Res. Serv., Libr. Congr., U.S. Gov. Print. Off., Wash. D.C.

Abstract

Reviews the problems of indexing environmental quality and the state of the art in measuring several categories of quality indices: air quality, water quality, pesticides and toxic substances, radiation, noise pollution, recreation. 46 refs.

Veal, A. J.

1974. Environmental perception and recreation: A review and annotated bibliography. Res. Memo., 58 p. Univ. Birm., Birm., England.

Abstract

A review of British and international research on perception and user attitudes in recreation. Contains an annotated bibliography of some 400 items. 400+ refs.

Wyckoff, J. B.

1971. Measuring intangible benefits: Some needed research. Water Resour. Bull. 7(1):11-16.

Abstract

A brief review of some of the methods available for valuing esthetic and recreational resources. 19 refs.

Critical Comments

Few details are provided.

INVENTORY METHODS

References in this section are inventories of physical and/or visual aspects of environments. Often they are quantitative inventories, i.e., inventoried items are converted by various means to arrive at numerical measures or ratings of environmental factors or of whole environments. The generated numbers may have a reasonable rationale behind them; most of the time, however, they do not.

Battelle Memorial Institute.

1973. Development of the Arizona environmental and economic tradeoff model. 172 p. Battelle Columbus Lab., Columbus, Ohio.

Abstract

A computer model was developed to describe environmental impacts of economic and demographic change and to evaluate trade-offs between economic development and environmental quality. Esthetics is one of the 4 categories of environmental quality studied, and is divided into 6 subcategories: land, air, water, biota, man-made objects, composition. All categories and subcategories are given numerical weightings to indicate importance. 21 refs.

Critical Comments

A comprehensive and seemingly sophisticated model, but no justification is given for the arbitrary weightings of elements of environmental quality. The model (ATOM) is dependent on users' subjective appraisals. ATOM has some utility, if used as a gaming/sensitivity model.

Burke, Hubert D., Glen H. Lewis, and Howard W. Orr.

1968. A method for classifying scenery from a roadway. Park Pract. Dev. Guidl. 22(1):125-141.

Abstract

A classification inventory system which evaluates the roadside environment in three observation zones (roadside zone, outer zone, and far zone) is presented. The procedure is based on comparisons of each of the viewing zones to the "characteristic landscape" for that zone. Photographs of 26 landscapes are evaluated to illustrate the application of the rating system. 6 refs.

Critical Comments

The identification of the viewing zones is arbitrary, but probably useful. The impact of man-made structures on the landscape is primarily dependent on the perceptual bias of the observer and the particular structure and cannot be evaluated uniformly as the authors imply.

Dearinger, John A.

1968. Esthetic and recreational potential of small naturalistic streams near urban areas. 260 p. Univ. of Ky. Water Resour. Inst., Lexington.

Abstract

"The purpose of this study was to find a way to evaluate the esthetic and recreational potential of small streams and their watersheds. Research was limited to naturalistic streams with drainage areas under 100 square miles and located within 25 miles of a city. A methodology, based on some previous work of the U.S. Soil Conservation Service and the principles or concepts of terrain analysis, land use planning, value judgment philosophy and the economics of outdoor recreation, was developed and applied in detail to two streams near Lexington, Kentucky.

Evaluations were made of the streams' potential for camping (primitive, transient and group), fishing, picnicking, a trail system (hiking, horseback riding, bicycling and auto tour routes), esthetic enjoyment (sightseeing, nature walks and walking for pleasure) and the establishment of natural, scenic and historic areas. Limited applications were also made to two other watersheds and to selected recreation sites on Boone and Jessamine Creeks. Extensions of these case studies resulted in procedures for estimating visitation to a developed site, future participation demand generated by an urban area and the proportion of that demand that would be satisfied at a specific site, and the economic benefits that would accrue if the sites were developed." 82 refs.

Critical Comments

This massive report presents a detailed, exhaustive, professional inventory and evaluation of the watersheds, but does not include public evaluations of the esthetic and recreational potential of the areas. The importance of public opinions is acknowledged in the section on public demand analysis; public opinions can be incorporated directly in the evaluation stages.

Fines, K. D.

1968. Landscape evaluation: A research project in East Sussex. Reg. Stud. 2:41-55.

Abstract

"A method of landscape and townscape evaluation is described. A worldwide scale of values was devised by testing a selected group with photographs to remove personal bias. A network of view evaluations is converted to land-surface values. A micro-evaluation of East Sussex is set against an outline evaluation of Britain; 'regional landscape value profiles' with parameters being illustrated. Applications of the technique and an example of route selection for a supergrid transmission line are explored. Methods of defining conservation areas by statistical techniques are described and a plea made for the recognition of areas important in relation to population and accessibility." 3 refs.

Critical Comments

Brancher, D. M. 1969. Critique of K. D. Fines: landscape evaluation. A research project in East Sussex. Reg. Stud. 3:91-92. Brancher objects to Fine's selecting only respondents with "considerable experience in design", assigning cardinal values to ordinal scales, representing extreme variety of landscapes with only 20 photographs, and other questionable criteria.

Hamill, Louis.

1971. Classification of forest land for recreational potential and scenery. For. Chron. 47(3):149-153.

Abstract

Proposes an intensive landscape inventory system including (1) reconnaissance, (2) identification of planned uses, (3) rating visual scenic attributes, (4) rating water attributes, (5) identifying and mapping needs for development, and (6) classifying for zoning and other policy decisions. In categories 3 and 4 the author

suggests analyzing landscapes, using such criteria as beauty, contrast, and harmony. The proposals are presented as general suggestions, not as detailed, organized procedures. 18 refs.

Critical Comments

The idea of using a standard landscape is good, though standardization can also be accomplished mathematically from quantitative evaluations.

Hamill, Louis.

1974. Statistical tests of Leopold's system for quantifying aesthetic factors among rivers. Water Resour. Res. 10(3): 395-401.

Abstract

"Leopold has published a set of techniques for comparing aesthetic factors among rivers, which include uniqueness ratios and graphic derivations of scale of river character and scale of valley character. The usual practice in evaluating Recreational and Scenic Resources is to use a consistent rating scheme and to derive summary measures of attractiveness by adding evaluation numbers or ratings. The latter procedures were used to test Leopold's methods by using the Spearman rank correlation coefficient to compare rankings by the two methods. There was poor correlation between evaluation numbers and uniqueness ratios for physical and water quality factors. Correlation was better for human use and scenic factors. The graphic procedures were found to introduce unexpected anomalies in combining two or more sets of factors, and the addition of evaluation numbers requires less time and effort than the procedures advocated by Leopold and is less subject to errors." 6 refs.

Critical Comments

A good critique of Leopold's method, but the alternative presented is not without fault either.

Headings

Statistical tests of ranking for selected factors; Rankings for scale of valley character; Rankings for scale of river character; Analysis of graphic derivations.

Handley, Rolland B., T. R. Jordan, and William Patterson.

1969. An environmental quality rating system. 45 p. U.S. Dept. Int., Bur. Outdoor Recreat., Northeast Reg. Off., Phila., Pa.

Abstract

Describes a system designed for rating the quality of natural and urban environments. "There are three numerical elements — base values, weighting factors and negative factors — values are arbitrary at this time. . . ." Eight categories or fields of interest were selected for rating. These were community resources, resident populations, landforms, leisure resources, vegetation, fish and wildlife, historical and archaeological matter. Each of 4 to 8 factors within a category is assigned a maximum achievable base value. The rater then decides how much of each factor is found in an area. Factors are also weighted before ratings are summed. Negative factors are then subtracted. 10 refs.

Critical Comments

Authors acknowledge their system is arbitrary, but recommend it for multiple ratings of one area, i.e., for measuring environmental changes. However, system arbitrariness is no less dangerous for such applications. Less arbitrary models are presently available.

Hart, William J., and William W. Graham.

1967. How to rate and rank landscapes. *Landscape Archit.* 57(2):121-123.

Abstract

A scheme to evaluate landscapes is based on the assumption that "a richly textured landscape offering many visual contrasts, enhances the environment" for recreational use. The procedure used to identify potential scenic recreational areas is to locate "folded" (vs. "smooth") areas on topographic maps using scales of 1:250,000 and 1:50,000 and to rate the areas identified according to various physical and biological factors present. The procedure is primarily an inventory method and is designed for use on a large regional scale. No refs.

Critical Comments

No empirical evidence is presented to justify the rating and ranking of elements selected.

Helliwell, D. R.

1967. The amenity value of trees and woodlands. *J. Arboric. Assoc.* 5:128-131.

Abstract

Each of seven factors "involved in determining the amenity value of a tree or wood" is assigned a rating from 1 to 4. Factors include crown area, life expectancy, position importance, presence of other trees, form, species in relation to setting, and special or historical value. Numerical ratings "are then multiplied together to give a figure corresponding to the amenity value. This figure can, in turn, be multiplied by a constant figure to obtain a monetary value. 1 ref.

Critical Comments

Model is extremely arbitrary.

Iowa State University, Department of Landscape Architecture.

1969. Souris-Red-Rainy River Basins. 54 p. *Dep. Landscape Archit.*, Iowa State Univ., Ames.

Abstract

Presents professional evaluations of the esthetics of three river basins. The study was conducted in three stages: (1) research concerning the physical features of the areas, (2) reconnaissance (air and field) and photography, and (3) synthesis. Evaluations are presented as verbal descriptions. General management recommendations are made. 18 refs.

Critical Comments

Provides only descriptive evaluations, not a systematic methodology that could be used by others.

Iverson, Wayne D.

1975. Assessing landscape resources — a proposed model. In *Landscape assessment: values, perceptions and resources*, p. 274-288. Ervin H. Zube, Robert O. Brush, and Julius Gy Fabos, eds. Dowden, Hutchinson, and Ross, Inc., Stroudsburg, Pa.

Abstract

Presents a technique for landscape assessment that is applicable to land areas in the range 25,000 to 250,000 acres. The use of VIEWIT (a seen-area computer program, Elsner 1971) is illustrated. A theoretical model is proposed for use with the VIEWIT

program to quantify landscape assessment. When combining categorical parameters through the use of VIEWIT and appropriate subroutines to obtain the total visual impact, equal weightings for all categories are suggested unless variable weightings can be justified experimentally. Scenic quality is rated on a 3 point scale based on variety. 19 refs.

Critical Comments

Perhaps equal weightings also should be justified experimentally. Equal weightings are just as arbitrary as unequal weightings.

Headings

Smith river highway visual analysis study; Mineral king visual analysis; A proposed model for landscape assessment quantification; Social sensitivity of the landscape view (types of viewers); Visual perception sensitivity (screening; angle of viewer land plane, distance); Contrast reduction potential (inherent ability, action to reduce contrast); Weighting systems.

Johnson, Christine G.

1974. Mineral King visual analysis. 52 p. U.S. Dep. Agric. For. Serv., Calif. Reg., San Francisco.

Abstract

Illustrates a method of combining the VIEWIT computer program (Elsner 1971) with the "Visual Resource Management System" as outlined in National Forest Landscape Management, Vol. 2 (USDA 1974). The output consists of computer maps of "scenic quality" (variety) and "ability to absorb visual modification" (based on texture analysis) and composite maps based on the number of times an area is seen (from a proposed travel corridor), angle of view, distance, ability to absorb visual modification and scenic quality. 1 ref.

Johnson, Hugh A., and Judith M. Huff.

1966. Toward measuring the intangible values of natural beauty. *Proc. 21st Annu. Meet. Soil Cons. Soc. of Am.*, 5 p. U.S. Dep. Agric., Econ. Res. Serv., Wash. D.C.

Abstract

The need to develop specific procedures to measure and evaluate beauty is necessary if esthetic concerns are to be incorporated into planning and management programs. The concept of beauty is discussed and Lewis' linear corridor theory for inventorying environmental values of landscapes is presented. 10 refs.

Jones, Grant R., Ilze Jones, Brian A. Gray, Bud Parker, Jon C. Coe, John B. Burnham, and Neil M. Geitner.

1975. A method for the quantification of aesthetic values for environmental decision making. *Nuclear Tech.*, 25:682-713.

Abstract

"The methodology for quantitative evaluation of visual impact considers the appearance and visual quality of a landscape setting as viewed from a series of representative viewpoints "before" and "after" the introduction of a nuclear facility. Procedures to select representative viewpoints are based on facility visibility from the surrounding area, viewing distance, observer position, and impacted viewing populations. A duplicate photo or slide taken from each representative viewpoint is touched up to portray the viewscape condition with the facility. The visual quality of each condition is then evaluated by applying the scaled measurements of intactness, vividness, unity, and importance of the major viewscape components, and these scores combined into a formula

yielding a visual quality rating from 1 to 100. Total visual impact of a proposed facility is the sum of visual impacts measured at each representative viewpoint, with the difference between before and after conditions expressed in terms of percent of change modified by population viewing contact. An expression of the relative scarcity or uniqueness of the potentially impacted landscapes serves to protect remote areas and unique natural and cultural features."

Critical Comments

The procedure is thoughtful, comprehensive, and appears to work. However, the quantitative, systematic rigor, and apparent objectivity mask the underlying arbitrariness of the approach. Especially arbitrary are the relative weights of the various components (e.g., 1:1). Empirical verification of the relative weights and the functional relationships are needed to validate the procedure.

Kaiser, Edward J., Karl Elfers, Sidney Cohn, and others.

1974. Promoting environmental quality through urban planning and controls. Socioeconomic Environ. Stud. Ser., EPA-800/5-73-015, 441 p. Off. Res. and Dev., U.S. Environ. Prot. Agency, Wash. D.C.

Abstract

Section on land use planning (p. 107-182) is the most relevant to visual landscape analysis. Several inventory methods are reviewed and the problem of assessing visual quality discussed. Most of the volume deals with problems of managing environmental quality. 462 refs.

Headings

Changing awareness and practice: perspectives of the 60's, the current scene in local and metropolitan planning agencies. Promising approaches: land use planning, water resources management, urban design, planning and residuals management.

Kiemstedt, Hans.

1967. Zur Bewertung der landschaft fur die Erholung. (Evaluation of the Natural Components of Recreational Landscapes.) Verlag Eugen Ulmer, Stuttgart, Ger. 150 p.

Abstract

Presents an evaluation system based on identification and quantitative ratings of various factors contributing to landscape quality (e.g., relief, water, grasslands, climate, edges). Various uses of scenic areas and distances from cities, etc., are also rated and are to be used as weights in determining the final score, "Vielfaltigkeitswert" (related to variety). 117 refs.

Critical Comments

Though written in German, it is included because of extensive (117) citations of relevant German literature.

Land Use Consultants

1971. The planning classification of Scottish landscape resources. 126 p. Countryside Comm. Scotl., Woods of Perth, Ltd., Perth, Scotl.

Abstract

Presents a detailed survey and classification of Scottish landscapes, based on analyses of maps, air photographs and field observations. Primary classifications are derived from measurements of landform + ground cover. Subclasses are based on the presence of water, "point artifacts" (e.g., settlements, buildings)

and communication networks. An inventory is made of the quality of landscape elements within each class. 177 refs.

Critical Comments

Authors suggest that public input would be valuable, but depend primarily on professional analyses. The volume is well illustrated and includes an extensive bibliography.

Leopold, Luna B.

1969a. Landscape esthetics. Nat. Hist. 78:36-45.

Abstract

An inventory method of esthetic quantification was developed to assess the esthetic uniqueness of Hell's Canyon as compared to 11 other river valleys in Idaho. No refs.

Critical Comments

See following reference.

Leopold, Luna B.

1969b. Quantitative comparison of some aesthetic factors among rivers. Geol. Surv. Circ. 620, p. 1-16. U.S. Dep. Int. Geol. Surv., Wash. D.C.

Abstract

Uniqueness ratios, based on physical factors, biologic and water quality, and human use and interest (consisting of a total of 46 esthetic factors), were developed for 12 Idaho River sites and 4 National Park river sites. A graphic/geometric projection technique was used. No refs.

Critical Comments

An early and innovative article. The author performed all ratings. Since the author defined the factors and then rated them, the potential for bias is inherent. Quantitative problems may arise from the lack of a theoretical foundation for definitions and averaging of ordinal data. Some of the potential criticisms are recognized by the author. No refs.

Leopold, Luna B., Frank E. Clarke, Bruce B. Hanshaw, and James R. Balsley.

1971. A procedure for evaluating environmental impact. Geol. Surv. Circ. 645, 13 p. U.S. Dep. Int. Geol. Surv., Wash. D.C.

Abstract

"This report contains a procedure that may assist in developing uniform environmental impact statements. The heart of the system is a matrix which is general enough to be used as a reference checklist or a reminder of the full range of actions and impacts on the environment that may relate to proposed actions." The matrix consists of 100 actions which cause environmental impact and 88 environmental conditions that might be affected. Each relevant action is then checked and evaluated on a 10-point scale of the magnitude and importance of the expected impact on environmental characteristics. 3 refs.

Critical Comments

The authors submit that "assignment of numerical weights to the magnitude and importance of impacts should be, to the extent possible, based on factual data rather than preference," but offer no systematic methods for doing so.

Leopold, Luna B., and Maura O'Brien Marchand.

1968. On the quantitative inventory of the riverscape. *Water Resour. Res.* 4(4):700-717.

Abstract

"In the vicinity of Berkeley, California, 24 minor valleys were described in terms of factors chosen to represent aspects of the river landscape. A total of 28 factors were evaluated at each site. Some were directly measurable, others were estimated. . . ." Each factor was rated on a 5-point scale to derive a uniqueness ratio. 8 refs.

Critical Comments

The descriptive inventory and uniqueness ratio procedures are, in part, dependent on the evaluators' perceptions and the 28 factors (chosen a priori). The authors recognize these weaknesses in the procedure and indicate directions for further study.

Lewis, Philip H., Jr.

1964. Quality corridors for Wisconsin. *Landscape Archit.* 54(2):100-107.

Abstract

A team of experts from different academic disciplines (soil scientists, botanists, architectural historians, anthropologists, foresters) inventoried the natural and scenic resources of the state of Wisconsin. Upon comparing areas of unusual resource potential selected by each discipline, it was discovered that geographic areas determined to be most desirable often coincided and formed linear patterns or "corridors" when projected on the state map. Optimal use and benefit from these environmental corridors is suggested through preventing development within them and encouraging cluster development on fringe areas. No refs.

Critical Comments

It may be possible to enhance areas or improve access to their unique beauty by development; preventing development is not always the best answer. This is primarily an inventory method, and as such cannot in itself predict the effects of change.

Linton, David L.

1968. The assessment of scenery as a natural resource. *Scott. Geogr. Mag.* 84:219-238.

Abstract

Derives esthetic quality ratings from maps of Scotland showing the regional variation of landform character and the distribution of land use. Various categories of landforms and land uses are rated from 0-8 and from -5 to +6, respectively. "Bonus points" may be given to special features within a category. The summed scores are then used to construct a composite assessment map. The map was "validated" by the subjective assessment of 2 professionals. 6 refs.

Critical Comments

Scales are arbitrary and based on subjective judgments of the author. The author does note, however, that his judgments are influenced by and represent social values.

Litton, R. Burton, Jr.

1968. Forest landscape description and inventories — a basis for land planning and design. USDA For. Serv. Res. Pap. PSW-49, 64 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Abstract

Describes six analytical factors and seven compositional types useful in recognition and description of scenic resources. Their application is illustrated by two inventories made to aid managers and landscape architects in planning and design. 45 refs.

Critical Comments

Well illustrated, detailed descriptions of the variables; however, some previous design experience may be necessary if variables are to be used consistently and effectively for scenic evaluations.

Headings

Factors of scenic analysis and observation; Distance (foreground, middleground, background); Observer position (inferior, normal, superior); Form; Spatial definition; Light (color, distance, direction); Sequence; Composition (panoramic, feature, enclosed, focal, undergrowth, detail and ephemeral landscapes); Landscape inventories.

Litton, R. Burton, Jr.

1972. Aesthetic dimensions of the landscape. In *Natural environments: studies in theoretical and applied analysis*. p. 262-291. John V. Krutilla, ed. Johns Hopkins Univ. Press, Baltimore, Md.

Abstract

The following generalized attributes of the landscape are identified: primary factors of recognition (form, space, and time variability), secondary factors of recognition (observer position, distance, and sequence), and six compositional landscape types: (1) panoramic landscape, (2) feature landscape, (3) enclosed landscape, (4) focal landscape, (5) forest (canopied) landscape, (6) detail landscape. Three esthetic criteria are suggested for evaluating landscapes: unity, vividness, and variety. To include landscape as a resource in planning studies there must be, first, an awareness of landscape aesthetics and, second, an esthetic landscape inventory that catalogues esthetic qualities. Esthetic inventories can be summarized on topographic maps through route studies (utilizing photographs, sketches, notes, symbols) of a specific visual corridor, or through reconnaissance of particular areas. Aerial photography, following field sampling procedures, provides a useful way to develop large scale inventory maps. Landscape inventories can provide a display against which specific planning strategies can be tested to determine the effect on esthetic qualities of the landscape. 40 refs.

Critical Comments

Craik's paper (1972, see p. 2) which appears in the same book, tests the usefulness of Litton's esthetic landscape dimensions scale.

Headings

Attributes of the landscape; Recognition factors; Form, space, time variability; Secondary recognition factors; Landscape compositional types; Aesthetic criteria; The landscape as a resource.

Litton, R. Burton, Jr.

1973. Esthetic resources of the lodgepole pine forest. *Manage. Lodgepole Pine Ecosyst. Symp.*, 14 p. Pullman, Wash., Oct. 9-11, 1973.

Abstract

"The lodgepole pine forest is examined from two standpoints: broad overviews and detailed observation from within — the nearview. The broad ecological amplitude of the species is recognized, but its role in the Rocky Mountain landscape is emphasized." 6 refs.

Critical Comments

A professional's discussion, not a proposed methodology.

Headings

The forest from outside (overviews); Land forms and water bodies; Vegetation type patterns, soils, & microclimates. The forest from inside (closeviews); Floor elements; Elements of types and stands.

Litton, R. Burton, Jr.

1974. Visual vulnerability of forest landscapes. *J. For.* 72(7): 392-397.

Abstract

"Certain characteristics can help predict the landscape's vulnerability or resistance to such man-made visual impacts as roads or timber harvest. The planner must recognize (a) landscape compositional types, (b) sensitive parts and locations, and (c) outside influences and inherent effect, such as orientation, climate, seasons, slope, and soil and vegetation surfaces. Some ranking on levels of visual vulnerability are suggested." 10 refs.

Critical Comments

Discusses the potential of nondetectable management of landscapes. Detectable manipulations can sometimes enhance scenic beauty, however.

Litton, R. Burton, Jr., Robert J. Tetlow, Jens Sorensen, and Russell A. Beatty.

1971. An aesthetic overview of the role of water in the landscape. *Natl. Tech. Inf. Serv. PB 207 315*, 283 p. U.S. Dep. Comm., Springfield, Va.

Abstracts

"Emphasizing the aesthetic aspect of fresh water in the landscape, this report explores the contributions of water to the environments of recreation and everyday life. To identify the values of water in this role, a classification framework is developed for native characteristics and these are considered together with man-made changes. Concentrating upon the visual landscape, the classification identifies *landscape units*, and *waterscape units*. Inventories of existing conditions as well as man-made elements and improvements are related to the characteristics of the units.

The scope of the study includes evaluation comparisons and suggests tangible ways in which water and its treatment can contribute to environmental quality. Also included are recommendations for needed policies, planning guidelines and research that should better promote environmental enhancement through relationships with fresh water streams and bodies."

Headings

Description and classification framework: Classification; Inventories; Evaluation. Classification of manmade elements and improvements related to the landscape setting and waterscape units: Structures and alterations in the landscape unit; Structures and alterations in the setting unit; Structures and alterations in the waterscape; Evaluation of manmade structures and alterations in the water oriented landscape.

Litton, R. Burton, and Robert H. Twiss.

1967. The forest landscape: some elements of visual analysis. *Proc. Soc. of Am. For. Meet.*, p. 212-214. Wash. D.C., 1967.

Abstract

"... purpose is to describe six factors of observation and scenic composition, to comment on their relevance to resource management, and to suggest the range of variation in their importance. They are: (1) distance, (2) light, (3) topographic form and contrast, (4) spatial definition, (5) observer position, and (6) sequence." 4 refs.

Critical Comments

Relevance and importance of these factors have not been validated empirically.

McHarg, Ian.

1966. *Design with nature*. 198 p. Nat. Hist. Press, N.Y.

Abstract

Graphically presents suitability of land for various uses, e.g., types of recreation, urbanization, based on physical features of the environment (also mapped). Emphasizes ecological perspectives. No refs.

Critical Comments

Evaluation of which types of landforms are appropriate for which land uses is based only on professional experience.

Headings

Introduction; City & countryside; Sea & survival; The plight; A step forward; The cast and the capsule; Nature in the metropolis; On values; A response to values; The world is a capsule; Processes as values; The naturalists; The river basin; The metropolitan region; Process and form; The city: process & form; The city: health and pathology; Prospect.

Melthorn, W. N., and E. A. Keller.

1973. Landscape aesthetics numerically determined. *Highw. Res. Rec.* 452:1-9.

Abstract

"The LAND ('landscape aesthetics numerically determined') system provides a preliminary method to quantify esthetic factors of a landscape and to visually inspect hierarchically ranked alternatives. The model is an extension of Leopold's concept of landscape uniqueness. Descriptive evaluation numbers for various landscape factors are used to derive indexes (of uniqueness) which are then used to evaluate and compare different landscapes." Topographic maps, aerial photos, and field work are employed. 1 ref.

Critical Comments

See criticisms of Leopold's methods (above) and Hamill (1974).

Methven, Ivan R.

1974. Development of numerical index to quantify the aesthetic impact of forest management practices. *Inf. Re. PS-X-SI*, 20 p. Petawa For. Exp. Stn., Chalk River, Ont., Can.

Abstract

Develops a simplified numerical index to quantify the esthetic impact of forest practices on particular stands or operating units, by hypothesizing an idealized normal observer on the basis of a

common empathy and the dominance of the visual response in human esthetic relations with the natural environment. The index is constructed from six esthetic variables which are assigned equal values in the form of arbitrary units, and which are selected on the basis of stated requirements and components: (1) species diversity or variety, (2) structural complexity, (3) forest view, (4) slash visibility, (5) pattern, and (6) boundary form.

A method for incorporating the index into a total economic-esthetic evaluation is also presented. 19 refs.

Critical Comments

The author attempts to place esthetic and economic values in the same model; however, the derivation of the former is quite arbitrary. Further, the assumption of "common empathy" needs to be validated (see Hendee and Harris 1970).

Michalson, E. L.

1970. A methodology for evaluation of wild and scenic rivers. 8 p. Water Resour. Res. Inst., Univ. of Idaho, Moscow.

Abstract

"The procedure adopted is to study — more or less independently, at first — fourteen subprojects each involving an activity related to the river. . . First, individual researchers will inventory the physical, biological, and human resources affecting each subproject. Second, the inventory data obtained will be used to make an economic evaluation of the current use of these resources and the potential benefits available from them. Third, these data will be used as a basis for projecting future resource use and values. . ." Results are published separately by the Institute. No refs.

Murray, Timothy, Peter Rogers, David Sinton, and others.

1971. Honeyhill: A systems analysis for planning the multiple use of controlled water areas. Inst. Water Resour. Rep. 71-9, Vol. 1 and 2, U.S. Army Engrs., Alexandria, Va. 726 p.

Abstract

"The first phase of the study was an inventory by map subdivisions of the existing resources of the Honeyhill area. . . The data on the area were stored, analyzed and displayed using computer graphic techniques developed by the investigators. The second phase. . . was the development of quality indices for visual quality, ecological damage, wildlife habitat, etc., which utilized pertinent parameters from the resource inventory. The quality indices were then related to possible land uses including recreation. Finally, the grid areas of Honeyhill were evaluated and ranked in terms of various uses. . . The third state. . . was the development and investigation of possible planning evaluation approaches" using a simulation model. 168 refs.

Critical Comments

The computer graphics are sophisticated and impressive and offer promise for resource planning and decision-making. Indeed, much of the "Honeyhill" work has been applied. One problem with this particular study is that "attractiveness" is defined by professional judgments only.

Ontario Ministry of Natural Resources

[n.d.] Design guidelines for forest management. 181 p. Hough, Stansbury and Assoc. Ltd., Toronto, Can.

Abstract

A manual "which attempts to establish practical guidelines that will be useful to the resource planning team at district and

regional level. . ." Presents detailed professional analysis of esthetic problems confronted in forest management. 70 refs.

Critical Comments

Authors note that "recent research has shown that the visually trained individual can, and does, represent the majority opinion of the general public" is perhaps too much of a generalization. Manual is extremely well organized and designed.

Headings

Planning for management; Forest management area; Manual framework (site protection, aesthetics); Roads — site protection; Roads — aesthetics; Landings — site protection; Landings — aesthetics; Cutting — site protection; Cutting — aesthetics; Reforestation — aesthetics; Utilities; Interpretation — aesthetics; Recreation — aesthetics; Special influence area.

Potter, Dale R., and J. Alan Wagar.

1971. Techniques for inventorying man made impacts in roadway environments. USDA For. Serv. Res. Pap. PNW-121, 12 p. Pac Northwest For. Exp. Stn., Seattle, Wash.

Abstract

"Four techniques for inventorying man made impacts along roadway corridors were devised and compared on the basis of type and quality of data obtained, types of maps produced, area covered, and relative cost and time requirements." No measures were made of degree of impact on scenic quality or preference. 11 refs.

Sargent, Frederic O.

1966. Ideas and attitudes — a scenery classification system. J. Soil and Water Conserv. 1966 (Jan.-Feb.):26-27.

Abstract

A scenery classification system based on the categories: "distance, interest, variety, special interest, and eyesores" is presented. "The system is designed to compare scenic resources within a planning region." Values from 0 to 5 are assigned to the distance, interest and variety factors according to specific criteria. Eyesores have negative values from 1 to 5, while special interests have positive values from 1 to 5, depending on the degree of time the factor "catches and holds the eye." The four factors are then summed to determine the total scenic value at each location evaluated. Additional comments at each site are also included. No refs.

Critical Comments

The procedure is arbitrary; values are assigned subjectively. The assumption of equal weights for the four factors is unvalidated; therefore, even the ordinal rankings may be questionable. While the procedure may differentiate distinctly different scenic areas, such extremes are identifiable without formal, mathematical models.

U.S. Department of Agriculture, Forest Service.

1972. Forest landscape management, Vol. 1. 137 p. U.S. Dep. Agric. For. Serv., North. Reg.

Abstract

A systematic and comprehensive analysis by landscape architects of the variables judged to contribute most to resource management decisions. Lists the pros and cons of alternative scenic treatments. 27 refs.

Critical Comments

A comprehensive coverage of the topic, beautifully illustrated. Pros and cons are not validated experimentally or otherwise.

Headings

Landscape management; Landscape management fundamentals; Seeing the visual resource (light, observer distance, observer position, sequence, landscape types, object analysis); Perceiving the visual resource; Applied landscape management; Topic areas (timber harvest, roads, structures).

U.S. Department of Agriculture, Forest Service.

1973. National forest landscape management, Vol. 1. USDA Handbook 434, 77 p. Wash., D.C.

Abstract

A training document used to illustrate the concepts, elements, and principles of a landscape management program which identifies physical characteristics of the landscape and analyzes the potential visual effects of management actions. 46 refs.

Critical Comments

An esthetically appealing document that may be considered a primer on the subject.

Headings

Characteristic landscape; Variety; Deviations from the characteristic landscapes; Dominance elements (form, line, color, texture); Dominance principles (contrast, sequence, axis, convergence, codominance, enframement); Variable factors (motion, light, atmospheric conditions, season, distance, observer position, scale, time); Landscape character analysis; Landscape management alternatives.

U.S. Department of Agriculture, Forest Service.

1974a. National forest landscape management, Vol. 2, ch. 1: the visual management system. USDA Handbook 462, 47 p. Washington, D.C.

Abstract

Application of the principles discussed in Vol. 1. Variety and sensitivity (based on number of viewers, duration of view, etc.) of scenic areas are analyzed and mapped for determination of management objectives. 3 refs.

Critical Comments

Though the premises are unvalidated, the mapping method is an impressive and possibly powerful planning tool. The volume is inviting, colorful, and easily followed. A useful glossary is provided.

Headings

Premises; Important terms (character type and subtype, characteristic landscape, distance zones, dominance elements, management activities); System process & scope; Variety classes (distinctive, common, minimal); Sensitivity levels (highest, average, lowest); Quality objectives (preservation, retention, partial retention, modification, maximum modification).

U.S. Department of Agriculture, Forest Service.

1974b. Recreation opportunity inventory and evaluation. USDA For. Serv. Res. Pap. R-1 74 006, 76 p. Washington, D.C.

Abstract

Proposes a system for rating "attractive" features of recreation areas (high, medium, low), visual resource characteristics (somewhat arbitrary numerical ratings, from -12 to +24), and "discord" elements such as pollution (5 levels from "none" to "severe"). Accessibility, capacity, and recreation opportunity variables are also considered. 14 refs.

Critical Comments

The authors state that this paper "focuses first upon people's preference," yet people are not asked for their preferences. Rather, this is a professional judgment inventory and is too complex for public use.

U.S. Department of Agriculture, Forest Service.

[n.d.] Quantitative analysis of the visual resource. 48 p. U.S. Dep. Agric. For. Serv., Landscape Archit. Branch, Div. Rec. and Lands, North. Reg.

Abstract

Employs a wide variety of analysis resources (e.g., maps, photos, inventories, etc.) to generate numbers representing the visual "appeal" of scenic areas. Underlying assumptions include: "...variety and uniqueness in objects are the overriding factors that create visual interest; variety in the visual resource can be assessed by counting the number of feature objects, the number of artificial objects, subtracting the latter from the former in recognition of their competitive relationship." No refs.

Critical Comments

Model is somewhat arbitrary. For example, the procedure assumes consistently negative values for "artificial" objects.

U.S. Department of Agriculture, Forest Service and Tahoe Regional Planning Agency.

1971. Scenic analysis of the Lake Tahoe region: A guide to planning. 37 p. Tahoe Plann. Agency, South Lake Tahoe, Calif.

Abstract

Contains three studies concerned with scenic beauty of the Tahoe Region: "Visual Pollution in the Lake Tahoe Basin" (McEvoy III and Williams), "Visual Landscape Units of the Lake Tahoe Region" (Litton and Shiozawa) and "Scenic Analysis of Principal Travel Routes in the Lake Tahoe Region" (Hagemeyer, Ostergaard, Noble, and Kirschenmann). All are inventories and/or descriptions of various natural and man made features of the region. No refs.

Vedenin, Y. A., and N. N. Miroshchenchenko.

1970. Evaluation of the natural environment for recreational purposes. *Ekistics* 31:223-226.

Abstract

"The purpose of the present paper is to suggest a method of grading areas from the point of view of the organization of large regions for prolonged recreation." Physical factors are analyzed and areas mapped for recreation preference. 6 refs.

Critical Comments

The approach is based upon physical factors only. Public evaluations are not included.

Walker and Havens Landscape Architects.

1973. An evaluation of the aesthetic values as related to the water resources of the Columbia-North Pacific Region. 93 p. Walker and Havens Landscape Archit., Eugene, Oreg.

Abstract

"The purpose of this study is to identify within selected river basins those areas of higher aesthetic value with respect to human experience. In addition, the report shows those areas with lower aesthetic value which may be modified without great loss of landscape amenity." A detailed inventory of the physical features of the region was used to derive numerical esthetic ratings which were mapped. Research on public esthetic evaluations is recommended. 34 refs.

Critical Comments

Beautiful publication with much detail concerning the physical characteristics of the region. Conclusions are based on subjective professional judgments.

Zube, Ervin H.

1970. Evaluating the visual and cultural landscape. *J. Soil and Water Conserv.* 25(4):137-141.

Abstract

This paper reviews the approach of the North Atlantic Regional Water Resources (NAR) study in evaluating the visual and cultural landscape of a large area on the Atlantic seaboard and how the interfacing of water and other development needs can be accommodated. To evaluate the landscapes, landscape inventory and landscape evaluation techniques were established. The landscape inventory technique is a hierarchical classification (landscape series, landscape systems, and landscape units). Also considered in rating the landscape are significant historic sites, state parks, and forests or other areas of unique vegetation or scenic value."

To interface the visual and cultural landscape concerns with 17 water-related needs in the planning study, seven broad sub-needs of visual and cultural landscape components were identified. These provide a guide for evaluating tradeoffs among the water management plans considered under alternative development strategies. 1 ref.

Critical Comments

"The more dominant the form, the less important the pattern" is the assumption used for weighting, as well as greater value means higher value. Validation is needed. Good in that it considers both economic and visual values in water management.

PUBLIC INVOLVEMENT

As noted throughout Section II, public perceptions of scenic beauty may provide useful information to managers of public lands. This section includes articles that have worked from this premise, employing techniques such as questionnaires, interviews, semantic differentials, bidding games, psychophysical methods, etc.

Acking, Carl Axel, and Gunner Jarle Sorte.

1973. How do we verbalize what we see? *Landscape Archit.* 64:470-475.

Abstract

Three experiments are reported which concern "the individual's experience of landscape" and the associated descriptive

elements. In the first experiment, 40 subjects judged 15 environments (presented as color slides) on seven-point semantic scales. Individuals were to assume they would stay in each of the environments for a 5-year period. Factor analysis indicated that the landscapes would affect the individuals by causing them to (1) feel more calm or aggressive, and (2) more silent or extroverted. The second experiment showed that landscape complexity received low values in pleasantness. In the third experiment, subjects identified objects that did not fit into the environment (non-unity) and listed their reasons. Results indicate that, in general, "unity is reduced if the elements are of permanent character, whereas complexity is increased when the intruding elements have a temporary character." 7 refs.

Critical Comments

The adjectives used in the semantic scales are somewhat nebulous and could be defined in many ways by the nonprofessional subjects.

Appleyard, Donald, and Mark Lintell.

1972. The environmental quality of city streets: The resident's viewpoint. *J. Am. Inst. of Plann.* XXXVIII:84-101.

Abstract

"Field interviews and observations were carried out on three similar San Francisco streets with differing traffic levels to determine how traffic conditions affected the livability and quality of the street environment. All aspects of perceived livability — absence of noise, stress, and pollution; levels of social interaction, territorial extent, and environmental awareness; and safety — were found to correlate inversely with traffic intensity. Traffic increases were also accompanied by the departure of families with children from these streets. Responses were nevertheless muted for a number of probable reasons, including environmental self-selection, adaptation, and lack of a target for resentment. The study is presently being replicated on a larger scale. Meanwhile, interim policies and standards are proposed." 21 refs.

Appleyard, Donald, Kevin Lynch, and John R. Meyer.

1964. The view from the road. 64 p. MIT Press, Cambridge, Mass.

Abstract

"Deriving its basic philosophy from the *Image of the City* (Lynch 1960), this book attempts to systematically record visual experiences while driving along the highway. Valuable primarily for some of its fresh approaches in methodology, *View from the Road* is designed as an experiment" (Harrison 1974).

Appleyard, Donald, Kevin Lynch, and John R. Meyer.

1967. The view from the road. In *Environmental perception and behavior*. p. 75-88. David Lowenthal, ed. Univ. Chic., Dep. Geogr., Res. Pap. 109. Chic., Ill.

Abstract

Presents general conclusions based on expressway travel studies in New York, Hartford, Boston, and Philadelphia. A multimedia procedure (tapes, films, photos, sketches) was employed to record the perceptual environment of the driver and passengers along the expressway routes. Analysis of the results led to the development of a graphic language reflecting the subject's perception and the incorporation of the graphic language into the basic design of two hypothetical expressways. A comprehensive summary of drivers' experiences along the expressways is reported with recommendations to make the "view from the road" a safe, educational, and esthetically pleasing experience. 1 ref.

Critical Comments

The method used to measure public preferences is not provided, only mentioned. Discussion appears to be based primarily on the researchers' intuitive analysis of the "View from the Road."

Boster, Ron S.

1973. On the criteria for and possibility of quantifying the esthetic aspects of water resource projects. *In* Toward a technique for quantifying of water resources. p. 6-12. Perry J. Brown, ed. PRWG-120-2, Utah State Univ., Logan.

Abstract

Twelve criteria are presented for consideration in evaluating esthetic quantification studies. The criteria are: (1) conducive to public involvement, (2) independent of the tastes and preferences of the developers of the technique, and statistically and mathematically unbiased, (3) theoretically sound, (4) separates the role of actual landscape features from the effects of observer standards including response bias, (5) adequately handles uncertainty of judgments, (6) cardinal or interval outputs, (7) easy to use, (8) relatively inexpensive, (9) meaningful, useable outputs, (10) regional applicability, (11) valid, (12) reliable. Applications of the Theory of Signal Detection to scenic preferences of wildland areas managed or treated in different ways is reported and evaluated against the 12 criteria. 13 refs.

Boster, Ron S. and Terry C. Daniel.

1972. Measuring public responses to vegetative management. *Proc. 16 Annu. Watershed Symp., Rep. No. 2*, p. 38-43.

Abstract

Presents a set of criteria "that might be used to judge techniques designed to quantify scenic beauty" and describes a new approach to scenic assessment, based on a "systematic conceptual model" of perception. The new approach, derived from the Theory of Signal Detection, produces cardinal indices of public perceptions of scenic beauty. The method employs color slide presentation and 10-point scenic beauty rating scales. It is easy to use and provides unbiased and meaningful indices of scenic beauty. 9 refs.

Brown, Perry J., ed.

1973a. Toward a technique for quantifying aesthetic quality of water resources. PRWG-120-2. 91 p. Utah State Univ., Logan, Utah.

Abstract

It is possible to quantify esthetic quality as it relates to water resources. Eleven criteria are suggested for providing a valid and operable quantification scheme. Concerns of colloquium members and directions for future research are suggested. Presentations by the colloquium members are included. 7 papers, 56 total refs.

Critical Comments

Papers presented in the volume represent some innovative thinking. See annotations of the papers (all 1973) by Boster, Brown, Cherem, Fuhrman, Gum et al., and Newby.

Brown, Perry.

1973b. Understanding scenes: Evaluation technique. *In* Toward a technique for quantifying aesthetic quality of water resources. p. 65-75. Perry J. Brown, ed. PRWG-120-2, Utah State Univ., Logan.

Abstract

Psychological research indicates that some or all of the following conditions are present when something is esthetically pleasing: (1) orderliness of the arrangements of elements in a scene, (2) stimulus complexity and/or psychological complexity, (3) the right amount of information (sic), (4) past learning experiences. Photographic procedures (by Shafer et al.) to evaluate esthetic appeal are reviewed. Validating photographic-esthetic evaluation procedures with on-site visitation is recommended. A generalized esthetic quality rating procedure is described, but has not been tested. 16 refs.

Bultena, Gordon L., and John C. Hendee.

1972. Foresters' views of interest group positions on forest policy. *J. For.*:337-342.

Abstract

"Foresters on five National Forests in the Pacific Northwest, when identifying special interest group positions on timber cutting, aligned themselves with commercial (as opposed to) recreational-aesthetic interest, viewing the latter as having unjustified expectations. On the issue of opening trails to motor bikes, foresters saw a split among recreational interests." A questionnaire method was employed.

Critical Comments

Questionnaires were given only to professional foresters, so results reveal foresters' perceptions of interest group positions. 25 refs.

Calvin, J. S., J. A. Dearing, and M. E. Curtin.

1972. An attempt at assessing preferences for natural landscapes. *Environ. and Behav.* 4:447-470.

Abstract

Observers were asked to judge 15 different views of natural scenery on each of 21 semantic scales. Factor analysis identified two factors which people use in their subjective assessments of natural scenery: scenic beauty and natural force-tranquility. Shafer et al. (1969, see p. 22) elements were included in a later factor analysis. 23 refs.

Carr, Stephen, and Dale Schissler.

1969. The city as a trip — perceptual selection and memory in the view from the road. *Environ. and Behav.* 1:7-35.

Abstract

This study attempted to measure how people perceive and remember their approach on an elevated expressway to the center of a city. Psychological studies are reviewed which relate eye movement and eye fixation to elements of the environment. Hypotheses of perceptual selection were proposed. Subjects (N=49), front seat passengers with headmounted eye movement recorders, were tested on the Northeast Expressway into Boston. Commuters and drivers without recorders were also tested. Statistical analysis of eye movements and memory tests strongly support the hypothesis that the form of the expressway actually structures the way in which people scan their surroundings and largely determines the elements they select for close attention. Common factors that caused visual selection of objects on the Northeast Expressway were identified and used by two judges to predict elements that travelers would focus on when using the Southeast Expressway. Field tests supported the judges' predictions based on the hypothesis that "major items that subjects will remember after an automobile trip into the city can be predicted primarily on the basis of the amount of time an item is in view." 25 refs.

Cherem, Gabriel.

1973. Looking through the eyes of the public or public images as social indicators of aesthetic opportunity. In *Toward a technique for quantifying aesthetic quality of water resources*. p. 52-64. Perry J. Brown, ed. PRWG-120-2. Utah State Univ., Logan.

Abstract

Kevin Lynch's (1960) concept of public images is investigated through "user employed photography" in a 700-acre wildlife sanctuary. Subjects (N=225) were given a 12-shot Kodak X-25 camera and a comment sheet and were asked to photograph any scene or object they wished while hiking along a chosen path and to record their reasons for taking each picture. Analysis of results suggested "change" as the explanation for scenes or objects consistently photographed. A twelve dimension "bipolar senso-environmental change rating scale" (equal weights for all dimensions) is developed to measure changes from one area to another. A public preference unit rating scale is suggested for evaluating areas where man made changes are anticipated to determine if the changes will increase or decrease esthetic quality. 2 refs.

Critical Comments

A very innovative study. The assumption that, "all dimensions of change are assumed to be equipotent in their effect on image strength," needs to be validated.

Clark, Roger N., George H. Stankey, and John C. Hendee.

1974. An introduction to Codinvolve: A system for analyzing, storing, and retrieving public input to resource decisions. USDA For. Serv. Res. Note PNW-223, 16 p. Pac. Northwest For. and Range Exp. Stn., Seattle, Wash.

Abstract

"Codinvolve is a flexible, content-analysis system specifically designed for objective analysis of public input — coding, storing, retrieving, summarizing, and displaying that input as it is needed. Codinvolve is based on a coding process which provides quantitative summaries of all opinions — and qualitative descriptions of supporting reasons. . . The concepts and criteria on which the system was based are discussed. General procedures for applying Codinvolve are explained." 4 refs.

Critical Comments

The authors admit that "coding is a demanding job, and not everyone can do it." Codinvolve depends on subjective interpretations of verbal communications; there may be a tendency (albeit unintentional) to treat results as more objective and systematic than they really are.

Cook, Walter L., Jr.

1972. An evaluation of the aesthetic quality of forest trees. *J. Leisure Res.* 4(3):293-302.

Abstract

"Twelve pairs of mature forest trees representing three classes of timber quality were selected along trails at three recreation sites in New York and Pennsylvania. A different hardwood species was selected at each site. Visitors compared the attractiveness of the trees within each pair, indicating their preference, and selected from a list those physical characteristics most responsible for their choice. The results indicated a positive relationship between esthetic quality and timber quality, especially in pairs representing very good and very bad timber quality. The relationship was somewhat erratic, however, indicating that timber quality classifications were not sufficiently discriminating, and did not encom-

pass all the criteria of esthetic quality. Characteristics most often marked as reasons for preference were: more balanced, more attractive background, straighter, and more branches." "Picturesque" trees are often appreciated on an esthetic dimension in spite of disease. A categorical assumption that a healthy tree is a beautiful tree is dubious. 4 refs.

Critical Comments

Comparative forced choice procedure leads to unbiased data, but presents some difficulty if more than a few sites (or trees) are to be compared and/or a large number of subjects are to be tested.

Costantini, E., and K. Hanf.

1972. Environmental concern and Lake Tahoe: A study of elite perceptions, backgrounds, and attitudes. *Environ. and Behav.* 4:209-242.

Abstract

Presents an analysis of interviews with 303 persons "who, by virtue of their activity, position, and reputation, were identified as having a significant impact on environmental decision-making in the Lake Tahoe Basin." The study utilized both structured and unstructured questions, as well as a questionnaire consisting of 84 4-point Likert-type statements ("strongly agree" to "strongly disagree") concerning environmental perceptions, attitudes, and solutions. Face validity assessment and "item analysis" were used to limit the list of Likert scales. Responses to 6 Likert items were then used to classify respondents as "high," "middle," or "low" in environmental concern. These three groups are contrasted in terms of their responses to the interviews. 12 refs.

Critical Comments

Likert scales included no neutral or undecided category.

Coughlin, Robert E., and Karen Goldstein.

1970. The extent of agreement among observers on environmental attractiveness. *Reg. Sci. Res. Inst. Discuss. Pap. Number 37*, 56 p. *Reg. Sci. Res. Inst.*, Phila., Pa.

Abstract

Judges were asked to rate environments on a scale from 1-7. Four groups rated photographs of watersheds, while one group rated scenes in the field. "Statistical tests revealed that judges are able to discriminate among environments on the basis of their attractiveness and tend to have a relatively high level of agreement on a given environment. . . The lowest levels of agreement were found when the judges were asked to rate slides with regard to functional attractiveness for living-in and for sightseeing, rather than for environmental attractiveness in the abstract. . ." Responses to slides tended to be consistent with responses to the same environments in the field. A relative preference for "natural" over "suburban" environments was noted. No refs.

Critical Comments

Provides validation for use of photographic representations of environments, for assumption that "natural" environments are preferred, and for procedures involving the public.

Coughlin, Robert E., Thomas R. Hammer, Thomas G. Dickert, and Sallie Sheldon.

1972. Perception and use of streams in suburban areas: Effects of water quality and of distance from residence to stream. *Reg. Sci. Res. Inst. Discuss. Pap. Ser.*, Number 53, 73 p. *Reg. Sci. Res. Inst.*, Phila., Pa.

Abstract

Onsite interviews, mail questionnaires, and chemical measurements of stream water quality were used to derive a statistical relationship between water quality and perception and use of streams. Results of regression analyses indicate that the less polluted a stream appears, the more it is liked and used. Dependent variables were derived from the questionnaire; independent variables included distance to stream, number of children, drainage area, a water quality index, and 16 chemical indicators.

Critical Comments

Interesting combination of survey results and physical measurements.

Craighead, Frank C., and John J. Craighead.

1962. River systems: Recreational classification, inventory, and evaluation. *Naturalist* 13(2):3-19.

Abstract

The authors propose a classification, evaluation, and rating system emphasizing "the qualitative aspect of the water resource and its esthetic role." Sample questionnaires evaluating boating, fishing and hunting resources are provided. Each questionnaire contains 12-13 criteria which can be used to rate a stream or watershed. 6 refs.

Critical Comments

Assignment of numerical ratings to descriptive criteria is arbitrary or subjective. Authors do not indicate whether professionals or non-professionals should do the evaluating.

Headings

Recreational classification; Size; Condition and use; Ecological sub-classes; Inventorying resources and evaluating quality; Quality evaluation; Rating criteria; Quality designation; Discussion of rating criteria for determining quality; Environmental effect; Populations; Success or satisfaction; Accessibility; Crowding; Research and management; Season; Conflicts; Size; Habitat; Pollution and littering; Hazards and barriers.

Craik, Kenneth H.

1968. The comprehension of the everyday physical environment. *J. Amer. Inst. Plann.* 34:29-37.

Abstract

Describes a model for studying environmental perception. Identifies important observer groups, various methods of presenting environmental displays, 14 possible judgment formats, and several validation criteria. 33 refs.

Critical Comments

Is especially useful for obtaining references on the possible judgment formats that can be used in evaluating environments and for viewing the range of possible observers and presentation modes.

Headings

Appraisal of inter-observer objectivity; Constructing landscape rating scales; Selecting a test set of diverse landscape scenes; Constituting panels of observers; Procedure; Appraisal of the reliability of the landscape rating scales and graphic landscape topology. The relationship of landscape dimensions and types to aesthetic appeal. Development and application of the landscape adjective check list.

Craik, Kenneth H.

1970. A system of landscape dimensions: Appraisal of its objectivity and illustration of its scientific application. Rep. to Resour. for the Future, Inc. 58 p. Inst. Pers. Assess. and Res., Univ. of Calif., Berkeley.

Abstract

Utilizes the landscape rating scale developed by Litton (1968) to identify the constituent elements present in slides representing 50 varied landscapes with minimal "signs of human activity or artifacts." In addition, a graphic "Landscape Typology" of 10 primary landscape types was used by reviewers in evaluating the 50 slides. Analysis showed that the landscape rating scale and the graphic landscape typology criteria are independent of the reviewing group. The slides were then categorized according to landscape dimensions in terms of how esthetically "pleasing" each slide was. A landscape adjective check list is developed, based on a sample of six slides. 23 refs.

Critical Comments

Numerous statistical tests are applied to a single set of data. A priori typological factors are found to be only *marginally* related to observer preferences, thus the validity of the system for use in the management of public lands is questionable.

Paper is very similar to 1972 paper: "Appraising objectivity of landscape dimensions." In *National environments: studies in theoretical and applied analysis*. p. 292-346. John V. Krutilla, ed. Johns Hopkins Univ. Press, Baltimore, Md.

Craik, Kenneth H.

1975. Individual variations in landscape descriptions. In *Landscape assessment: Values, perceptions, and resources*. p. 130-150. E. Zube, J. Fabos, and R. Brush, eds. Dowden, Hutchinson and Ross, Stroudsburg, Pa.

Abstract

Professionals and nonprofessionals were given "tours" through an area of Marin County, California by auto, by color film of an auto tour, by simulated tour of a scale model of the area, or by viewing a black and white video tape of the simulated scale model tour. Subsequently, they were asked to describe the tour using a "landscape adjective check list" and to describe themselves on a number of standard personality and attitude measures. Only the results of the auto tour observers are discussed.

Factor analysis revealed four factors accounting for 65 percent of the commonality. Sixteen groups of respondents ("O-types") responding differentially to the four factors were identified. Personality and environmental perception were related. 19 refs.

Critical Comments

This is an interesting study which carries management implications. Results suggest, for example, that some people tend to communicate their perceptions to the proper agencies, but these people comprise an O-type with one of the lowest memberships and with perceptions substantially different from those of other O-types.

Daniel, Terry C., and Ron S. Boster.

1976. Measuring landscape esthetics: The scenic beauty estimation method. USDA For. Serv. Res. Pap. RM-167, 66 p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

Abstract

"The Scenic Beauty Estimation Method (SBE) provides quantitative measures of esthetic preferences for alternative wild-land management systems. Extensive experimentation and testing

is reported along with applications employing user, interest, and professional groups. SBE shows promise as an efficient and objective means for better assessing the scenic beauty of public forests and wildlands and also for predicting the esthetic consequences of alternative land uses. Extensions and modifications of the basic methodology offer potentially useful design, planning, and management tools." 41 refs.

Daniel, Terry C., Lawrence Wheeler, Ron S. Boster, and Paul R. Best, Jr.

1973. Quantitative evaluation of landscapes: An application of signal detection analysis to forest management alternatives. *Man-Environ. Syst.* 3(5):330-344.

Abstract

Presents a scenic beauty measurement technique based on the Theory of Signal Detectability (TSD), a psychophysical measurement model that distinguishes between observer sensitivity and criterion state. Two questions are addressed: (1) can observers discriminate reliably among various vegetative treatments, and (2) do observers make differential esthetic responses to the various treatments? The method is applied to evaluation of Northern Arizona ponderosa pine forests. Color slides of the study areas were rated on 10-point scenic beauty rating scales and analyzed using the TSD technique. The slide presentation technique was validated by onsite judgments. 21 refs.

Dunn, Michael C.

1973. Scenic routes and recreation planning: The Teme Valley experiment. Res. Memo. Number 27, 38 p. Univ. of Birm., Eng.

Abstract

Describes an experiment carried out in the summer of 1973 by the West Midlands Tourist Board to set up and evaluate the use of a scenic drive. Presents the analysis of a questionnaire survey of a small sample of users and discusses the policy implications of the experiment.

Fabos, Julius Gyula.

1973. Model for landscape resource assessment. Mass. Agric. Exp. Stn. Res. Bull. Number 602, 141 p. Coll. Food and Nat. Resour., Univ. Mass., Amherst.

Abstract

This model makes use of both public attitude surveys and extensive physical inventories of ground and surface water quality and supply, wildlife productivity, agricultural productivity, visual and use complexity and compatibility, and tree cover. The public survey consisted of numerous Likert scales (strongly agree to strongly disagree) and ranking of the values of eight general resource variables. Public values are translated into coefficients (0, .2, .4, .6, .8, 1.0) designed to modify inventory values. Public attitude coefficients were not used in the pilot study as they did "not exert an important influence on composite resource value" in this instance. All coefficients exceeded .8. 137 refs.

Critical Comments

Many Likert items are rather difficult to understand. This probably did not present problems for the many professional respondents, but may have been an obstacle for other respondents and may help explain low response rates (from 12 to 30 percent for many subsamples). Ranking items were very general and difficult to conceptualize and compare. The lack of discrimination among public attitude coefficients suggests a need to force respondents into tradeoff decisions where tradeoffs are necessary in the real world.

Headings

The state of metropolization; Guidelines (principles) for landscape planning and landscape resource assessment models; Sub-models for the measuring and rating of the values of landscape resource variables; Application of the initial model to the study area.

Fowler, Ronald L., and Richard L. Bury.

1973. Visitor evaluations of a developed outdoor recreation area on a national wildlife refuge. In *Human dimensions in wildlife programs*, p. 50-56. John C. Hendee and Clay Schoenfeld, eds. Mercury Press, Rockville, Md.

Abstract

This study represents an attempt to determine the attitudes, characteristics, and satisfaction levels of visitors to a wildlife refuge in Georgia. Nine semantic scales and 25 modified Likert rating scales were employed. Factor analysis and analysis of variance revealed that visitors feel commercialism is inappropriate on game reserves. However, "there is no such thing as an average visitor. . . various groups perceive the refuge differently; consequently, the visitor could be provided a choice of several alternative experiences." 10 refs.

Gauger, Stephen E., and J. B. Wyckoff.

1973. Aesthetic preferences for water resource projects: An application of Q methodology. *Water Resour. Bull.* 9(3): 522-528.

Abstract

This study was designed to investigate whether esthetic preferences related to water projects could be determined, and whether they differ among different groups of people. A "Q sort" of 44 photographs of a wide variety of water development projects was conducted with two groups, photographers ("esthetic man") and town assessors ("economic man"). The resultant analysis identified two significant factors. Factor 1 provided insight into a hypothesis of nature-dominant or man-dominant scenes. Factor 2 indicated that the respondents had a negative preference for projects which were in varying stages of completion or appeared to be polluted. Preferences were consistent between the two groups tested. The test revealed that people do not necessarily equate only naturalness with esthetic appeal, but will accept development as esthetic, provided that it is designed to complement the natural landscape. 7 refs.

Gould, Peter.

1966. On mental maps. Mich. Inter-Univ. Community Math. Geogr. Discuss. Pap. Number 9, 54 p. Univ. of Mich., Ann Arbor.

Abstract

Students ranked states in order of their preferences for residential living. Results are presented by an iso-preference map. No refs.

Critical Comments

Mapping technique has potential by illustrating scenic preferences.

Gratzer, Miklos A., and Robert D. McDowell.

1971. Adaptation of an eye movement recorder to esthetic environmental mensuration. Storrs Agric. Exp. Stn., Res. Rep. Number 36. 29 p. Coll. Agric. and Nat. Resour., Univ. of Conn., Storrs.

Abstract

Reports on a new apparatus for the recording of human eye movements of subjects scanning landscape photographs. The results indicate that the method is suitable for mass use, requires no clinical facilities or ocular anesthesia and is fast and accurate. Most fixation points seem to accrue along "edges" and on small objects. Although there appears to be no universal scanning pattern, individuals are consistent in their own scanning pattern. 9 refs.

Critical Comments

Results are consistent with other studies which argue that contrast, variety, complexity, etc. are important esthetic dimensions. This is an innovative experimental method for identifying important landscape components, but the equipment may be too expensive for many research budgets.

Gum, Russell, Robert Judge, Dan Kimball, and Weston Wilson. 1973. Quantifying aesthetic quality of water resources. In *Toward a technique for quantifying aesthetics of water resources*. p. 32-51. Perry J. Brown, ed. PRWG-120-2. Utah State Univ., Logan.

Abstract

A research procedure "based upon a lexicographic analysis of people's perceptions of the components of aesthetic opportunity in combination with a modified Delphi process" is reported. Several methods (Thurston paired comparison test, Comrey paired allocation test, a rank order test, a simple average rating test, and a rating test based on the Theory of Signal Detection) are compared in establishing a weighting system for the esthetics of air (visibility, odor, irritants), water (clarity, floaters, odors), landscape (urban, mountain, desert, agriculture, forest, water dominated), biota (population, variety, healthy, location), and sound (background and intermittent). A Cobb-Douglas preference function is suggested for each esthetic category, e.g., air, water, etc., as a mathematical model to determine the elasticities of the subgoals, thereby establishing a tradeoff hierarchy. Esthetic preferences can be presented on three levels: (1) "average" or representative preference functions, (2) individual preference functions, and (3) grouped preference functions representing a "stereotype" of individuals with similar preference functions. Grouped preference functions (based on cluster analysis) are recommended as the most useful preference functions to incorporate into overall planning strategies. 12 refs.

Critical Comments

An interesting and fairly comprehensive investigation. The use of the Cobb-Douglas equation (commonly used by economists) is innovative; however, its effectiveness for this application is not validated.

Hampe, Gary D., Verne E. Smith, and James P. Mitchell. 1974. Water-related aesthetic preferences of Wyoming residents. *Water Resour. Res. Inst.*, Ser. Number 46, 111 p. *Water Resour. Res. Inst.*, Laramie, Wyo.

Abstract

"The water-related aesthetic values of 237 individuals are analyzed. This study is one of the first to use color photographs on a general population. Important differences were found by age and educational level." Scenes are classified into 8 types, depending on the type of water, mountains, man made objects, or people in the scenes. Respondents were asked first to rank their preferences for scenes within each type, then to rank the scenes between types. Multiple t's and stepwise regressions were used to analyze the data. 16 refs.

Critical Comments

Multiple t's present the problem of alpha slippage. Other analyses would have been more appropriate for multiple comparisons (e.g., ANOVA with post hoc testing).

Hancock, H. K.

1973. Recreation preference: Its relation to user behavior. *J. For.* 71(6):336-337.

Abstract

A questionnaire was used to determine how well campers' opinions about campsite vegetation agree with the behavior and opinions of subsequent campers selecting the same campsites with less vegetation. The study involves "campsite choices of 280 transient camping parties. . ." in the Cache National Forest, Utah. In general, decreased vegetation increased the selection of a campsite until a minimum threshold (virtually no vegetation) was attained—a finding contrary to opinions expressed by previously surveyed campers that the existing level of vegetation was optimum, and that a lower level would be less desirable. 4 refs.

Critical Comments

The study seemed tightly controlled. The surprising results may point to inherent problems with nonbehavioral models such as questionnaires (as employed in this study) and simple expressions of preference. Another possible explanation may be that preference may not be a good predictor of use; factors other than aesthetics (or, in this case, vegetation) may control site selection for recreation use.

Heberlein, Thomas A.

1973. Social psychological assumptions of user attitude surveys: The case of the wilderness scale. *J. Leisure Res.* 5(3):18-33.

Abstract

"Surveys of user attitudes often neither help managers meet user needs nor preserve recreational resources because these studies have little grounding in attitude theory.

Three issues in attitude theory are discussed and their relevance for user attitude surveys illustrated with examples from the wilderness scale developed by Hendee and associates (1968).

The organization of attitudes—vertical and horizontal structures and their centrality to the actor—is as important as individual preferences. It is unlikely that knowledge of user attitudes can help the manager either predict or change user behavior since the bulk of empirical material studies suggest there is no clear linear relationship between single attitudes and behavior.

Evidence is presented to show that the possibility of changing user attitudes is very low." 27 refs.

Critical Comments

Some recent studies have shown that attitude change, particularly concerning scenic resources, is possible.

Hendee, John C., and Robert W. Harris.

1970. Foresters' perception of wilderness-user attitudes and preferences. *J. For.* 68(12):759-762.

Abstract

A questionnaire completed by 1350 wilderness users and 56 forest managers identifies attitudes relating to "pureness of their perspective" of wilderness, policy and management alternatives, and expected behavior and customs. Results indicate that the perceptions of forest managers about wilderness users' attitudes are accurate in many viewpoints but inaccurate in others.

This observation points to the need for more frequent and extensive sampling of wilderness users' attitudes. 15 refs.

Hendee, John C., William R. Catton, Jr., Larry D. Marlow and C. Frank Brockman.

1968. Wilderness users in the Pacific Northwest—their characteristics, values, and management preferences. USDA For. Serv. Res. Pap. PNW-61, 92 p. Pac. Northwest For. and Range Exp. Stn., Seattle, Wash.

Abstract

This comprehensive study of wilderness users is based on the responses of 1350 persons to a questionnaire. One finding suggests some of the behaviors respondents sanctioned are inconsistent with sustaining the high quality of the wilderness resources. Public education may be needed. 44 refs.

Headings

The need for insight into wilderness users' tastes and preferences; Wilderness management not a majority vote problem; Visitors to three areas were studied; Questionnaires—the basic research tool; Demographic characteristics of wilderness users; Differentiating wilderness users by their attitudes; Other research classifying wilderness users; Wilderness-user behavior and attitudes toward management policies; Management preferences for wilderness-type areas; Management preferences summarized.

Hendrickson, P. O., R. W. Bahl, B. A. Gray, and W. S. Maynard.

1974. Measuring the social attitudes and aesthetic and economic considerations which influence transmission line routing. 121 p. Battelle Pac. Northwest Lab., Richland, Wash.

Abstract

"...described three slightly different approaches to evaluate visual quality of a view using a questionnaire on which the individual quality indicators of intactness (apparent degree of natural condition), vividness (memorability of the visual impression received from an image), and unity (compositional integrity, harmony and coherence) were separately rated for the 'before' and 'after' photos. A rating was also given to the visual importance of each element in the view...two scores were then placed into a ratio to express the severity of the change in visual quality relative to the 'before' quality score. 'Visual impact' was then expressed as a product of the ratio of change in visual quality and the size of the viewing population." The procedure takes into account the frequency of viewer contacts with a particular scene.

The authors recommend appraisal by a panel of five, four of whom are representatives of the "general public." 101 refs.

Critical Comments

The purpose is to measure change in landscapes due to introduction of transmission facilities, but the method does not distinguish between positive and negative changes. With larger samples, standardization, and inclusion of positive changes, this could be a very informative technique. Use of photos makes this questionnaire more reliable than most. Esthetic evaluation is but one section of the paper.

Headings

Review of the state of the art of transmission line routing; Measurement of social values; Quantification of aesthetic criteria; Measuring the social costs of transmission tower lines: A property value approach.

Kansas City, Missouri City Planning Department.

1967. Measuring the visual environment. Community Renewal Prog., Tech. Rep. 11, 80 p. City Plann. Dep., Kansas City, Mo.

Abstract

This is a pilot study for an inventory method that is designed to study entire cities. A survey was made of the "legibility" (colority, vividness, visual quality) of the cityscape of a small section of Kansas City. Trained observers examined the city by field reconnaissance and 37 citizens ("a balanced cross-section of the general population characteristics") were asked to give their impressions of certain areas by (a) sketching maps or diagrams, (b) listing distinctive elements, or (c) describing the location of particular city features. These surveys were followed by more intensive city reconnaissance and more public interviews. Results are synthesized into maps and recommendations for city improvements are made. No refs.

Kaplan, Rachel.

1973. Predictors of environmental preference: Designers and "clients." In *Environmental design research*. p. 254-264. W. F. E. Preiser, ed. Dowden, Hutchinson, and Ross, Stroudsburg, Pa.

Abstract

This study explored the relationship of "coherence" and "mystery" to preferences for slides of outdoor environments. Monochromatic slides, half graphic and half photographic, were rated on 5-point scales of preference, mystery (to what degree do you think you would learn more if you could walk deeper into the scene?), and coherence ("to what degree does it hang together?").

"Highly significant differences were obtained in the preference patterns of the three samples: Students in architecture, landscape architecture, and the College [U. of Michigan]." Architecture students rated urban environments higher and natural environments lower than the other two groups.

Graphic presentations were "difficult to understand" and thus excluded from the analyses. Mystery and coherence were found to be relatively independent and effective predictors of environmental preference. 12 refs.

Critical Comments

There is no indication that ratings were standardized, but partial *r*'s are calculated separately for each group.

Kaplan, Stephen.

1975. An informal model for the prediction of preference. In *Landscape assessment: Values, perceptions, and resources*. p. 92-101. E. H. Zube, J. G. Fabos, and R. O. Brush, eds. Dowden, Hutchinson, and Ross, Stroudsburg, Pa.

Abstract

Describes the process of identifying six variables which seem to have some role in the prediction of preference: complexity, mystery, coherence, identifiability, texture, spaciousness. Some evidence is empirical, some theoretical. See studies by R. Kaplan (1973), Kaplan et al. (1972), and Wohlwill (1968). 27 refs.

Kaplan, Stephen, Rachel Kaplan, and John S. Wendt.

1972. Rated preference and complexity for natural and urban visual material. *Percept. and Psychophys.* 12(4):354-356.

Abstract

Eighty-eight female subjects were shown 56 slides that represented a continuum of environments from "nature, to a predom-

inance of nature, to a predominance of man made aspects, to the urban scene." Using 5-point scales the subjects rated the randomly ordered slides on five factors, indicating their preferences for and the complexity of each slide. Rating results were used to classify the slides into four environmental domains and to summarize scenic preferences. Nonurban scenes were consistently preferred to urban scenes. Greater complexity within the natural and urban domains was preferred, but the role of complexity in determining preferences across domains was minimal. 13 refs.

Kooyoomijian, K. Jack, and Nicholas L. Clesceri.

1974. Perception of water quality by select respondent groupings in inland water-based recreation environments. *Water Resour. Bull.* 10(4):728-744.

Abstract

"This paper examines four lake environments which are paired by lake size and by trophic state, where trophic state is employed as an identifier of water quality. Two large lakes and two intermediate-sized lakes, with each pair having one oligotrophic lake and one eutrophic lake, are selected for cross-sectional survey-oriented questionnaire research. This paper focuses upon one aspect of the research, namely, the perception of water quality by three user groups. . . The groups are compared utilizing percentage response profiles and cluster level groupings. It appears from a preliminary analysis of the data that the lakes selected are viable trophic state endpoints for questionnaire analysis of respondents. Each user group surveyed does appear sensitive to select water quality parameters. . . Shifts in sensitivity appear within and between user groups with changes in ecological settings, as well as with factors independent of ecological settings." 13 refs.

Critical Comments

Incidence of returned questionnaires was very low (7-28 percent), making conclusions and generalizations questionable. The paper is somewhat easier to understand than the abstract (e.g., terms are defined early in the paper).

Leuschner, William A., and Roscoe B. Herrington.

1971. The skier: His characteristics and preferences. *In* *Recreat. Symp. Proc.*, p. 135-142. Northeast For. Exp. Stn., Upper Darby, Pa.

Abstract

Comparisons are made concerning skier characteristics and preferences from three regional surveys and a survey by a ski magazine. In general, "day skiers ranked proximity as the most important reason for skiing at a particular area. The physical quality of ski slopes (not including snow quality) was ranked second by the day skiers and first by skiers planning weekend and vacation trips." 5 refs.

Critical Comments

All data have previously been published elsewhere. This paper compares the regional characteristics. Basically, this is a confirmation of the apparent.

Lime, David W., and Charles T. Cushwa.

1969. Wildlife esthetics and auto campers in the Superior National Forest. USDA For. Serv. Res. Pap. NC-32. 8 p. Northcent. For. Exp. Stn., St. Paul, Minn.

Abstract

"Many resource managers feel that a high percentage of excursions to forested areas are planned with the objective of

seeing wildlife in mind. However, a study of campers (open-ended questionnaire) in the Superior National Forest did not show wildlife to be a primary attraction to the area, although it was an important supplementary attraction." The questionnaire revealed much ignorance concerning wildlife. More information should be provided to campers. 8 refs.

Critical Comments

The procedure (open-ended questionnaire) may not have been sufficiently sensitive to determine the importance of wildlife. Eighty-nine percent of the respondents had previously visited the area and 90 percent saw wildlife during the trip in question. Ninety-six percent of these people indicated that wildlife added to the outdoor experience, suggesting that wildlife may be more than a "supplementary attraction."

Merriam, L. C., Jr., and R. B. Ammons.

1964 67. The wilderness user in three Montana areas: Bob Marshall Wilderness, Mission Mountains Primitive Area, Glacier National Park. 56 p. Sch. of For., Univ. of Minn., St. Paul.

Abstract

The attitudes of wilderness users and park visitors about the "characteristics of wilderness," what constitutes a wilderness experience, and what management policies should be followed were obtained through an open-ended questionnaire administered by direct interview. The study areas exhibit different levels of human development which were reflected in the various respondents' concepts of a wilderness experience. The need to manage different types of wilderness areas in different ways was made apparent through the variety of responses. Suggestions for further studies were included. 30 refs.

Critical Comments

The authors note the following weaknesses in their analysis: A. Small samples (the samples may not have been of sufficient size). B. Variations in the study that were not controlled: "1. Differences in individual interviewer techniques, 2. Interview times and locations, 3. Some people are talkative while others are not."

Milbrath, Lester W., and Robert C. Sahr.

1974. Perceptions of environmental quality. Pap., VIII World Congr. Int. Soc. Assoc., 39 p. [Toronto, Can., August 23, 1974].

Abstract

Interviews were used to obtain judgments of the environmental quality of natural physical environments, dwelling environments, activity environments, and community characteristics. Various elements within these classes were rated on polar adjective scales, e.g. pleasing to displeasing, absolutely essential to not important, dull to exciting. Ratings on the "pleasing-displeasing" scale were used as environmental quality indices.

Critical Comments

History of the development of the survey is very complete and informative. Inclusion of a rating category "inadequate information to judge" is a strong point; however, results would be easier to understand and use if respondents had been given considerably more information.

Headings

Conceptualizing the measurement problem; Definition of environment; Theoretical premises behind the operationalization; The instrument development process; Pilot study; Leaders pro-

jections about public beliefs; Validity and reliability; Constructing an index of environmental quality; The relationship of environmental quality to quality of life.

Moeller, George H., Robert MacLachlan, and Douglas A. Morrison.

1974. Measuring perception of elements in outdoor environments. USDA For. Serv. Res. Pap. NE-289, 9 p. Northeast For. Exp. Stn., Upper Darby, Pa.

Abstract

"The meanings of 10 general concepts that describe elements of natural outdoor environments and experiences were measured with the semantic differential technique. Each element or concept was evaluated in terms of semantic scores on three factors of meaning—evaluation, potency, and activity. A total of 180 recreationists were surveyed—60 from each of three recreation groups. Similarities and differences were found among the three groups—campers, picnickers, and wilderness hikers—in the way in which they perceived each other and elements of recreation environments. Although they are tentative, study results should contribute toward a better understanding of the way in which people relate to outdoor environments and what they expect from those environments." 11 refs.

Critical Comments

The authors admit that the elements being evaluated need to be defined more precisely. Respondents evaluated general terms such as National Forest, wilderness, state park, etc. This study is offered primarily as a demonstration of a methodology.

Morisawa, Marie.

1970. Evaluating riverscapes. In *Environmental geomorphology*. p. 91-106. Donald R. Coates, ed. First Annu. Geomorphol. Sym. Ser. Proc. [Binghampton, N.Y., Oct. 16-17, 1970].

Abstract

"Analyses of aesthetics are made in terms of spatial relationships, arrangements of lines and masses, light, color, and appeal to other senses. In this study two approaches are being used in aesthetics of riverscapes: (1) an 'expert's' evaluation of vista, color, vegetation, spaciousness, serenity, naturalness, ripples, turbidity and pollution, and (2) analysis of ratings by viewers of riverscape slides. Indications are that ratings of viewers and 'experts' are similar, that preferences are general, and that evidence of man's interference lowers the beauty value." 9 refs.

Critical Comments

Proposals are made to relate preferences to physical features in a manner similar to that of Daniel and Boster (1976).

O'Riordan, Timothy.

1971. Public opinion and environmental quality: A reappraisal. *Environ. and Behav.* 3(2):191-214.

Abstract

Presents a case study in which opinion polls were used to gather information on public perceptions of water quality. The effects of this and other types of public opinion inputs are discussed. 47 refs.

Critical Comments

Contains an extensive bibliography on public perceptions of pollution of various sorts.

Pendse, Dilip, and J. B. Wyckoff.

1974. A systematic evaluation of environmental perceptions, optimum preferences, and trade-off values in water resource analysis. *WRR-25*, 86 p. Water Resour. Res. Inst., Oreg. State Univ., Corvallis, and Univ. of Mass., Amherst.

Abstract

"The specific study objective was to ascertain trade-off values for five environmental features: floods, water recreation, scenic view, wilderness, and a historical camping and recreation park. A simulated market experiment based on the PET (Priority Evaluation Technique) was the basic methodology applied. Five environmental variables (features) divided into three subsituations were depicted in black and white drawings highlighting environmental features and/or man-made features. Each situation was 'priced' and respondents indicated their satisfaction trade-offs under different budget (income) conditions. . . respondents valued removal of flood dangers above other considerations." Data were gathered via extensive interviewing. Procedure is an indirect approach to bidding. 46 refs.

Critical Comments

This is an interesting method for valuing scenic resources.

Peterson, George L.

1967. A model of preference: Quantitative analysis of the perception of the visual appearance of residential neighborhoods. *J. Reg. Sci.* 7(1):19-31.

Abstract

Visual appearances of residential neighborhoods were simulated by "a set of twenty-three color photographs. . . selected as representative from a quasirandom group of 100 taken in the northern half of the Chicago Metropolitan Area." Subjects (N = 140) rated the pictures on 10 dimensions: preference, greenery, open space, age, expensiveness, safety, privacy, beauty, closeness to nature, and quality of photography. Factor analysis and multiple regression techniques were used to combine common factors and determine their relationship to visual preference. Visual preference was found to be a function of four factors: harmony with nature (greenery, privacy, and open space), physical quality (age, expensiveness), "noise" (extraneous factors, undefinable in terms of the original ten factors) and quality of the photograph. 11 refs.

Critical Comments

Good, systematic development of a preference model.

Peterson, George L., and Edward S. Neumann.

1969. Modeling and predicting human response to the visual recreation environment. *J. Leisure Res.* 1(3):219-237.

Abstract

"A strategy is proposed for measuring and analyzing human preferences for the visual recreation environment. The aim is to develop quantitative preference functions which are sensitive both to individual differences and to visual characteristics of the environment. The strategy employs available measurement tools and statistical methods. . . Black and white photographs were used to elicit perceptions of and preferences for gross visual characteristics of a variety of beaches. Data acquisition proceeded in two stages, beginning with free responses to identify variables and culminating in the use of semantic differentials to measure selected attributes." Results identified two groups having distinctly different preferences. "One of the two groups prefers scenic natural beaches, is attracted by trees and natural growth, and finds crowding dis-

tasteful. The other group prefers city, swimming beaches, and is sensitive to the quality of the sand and attractiveness of surrounding buildings. It was determined, tentatively, that the two groups were using beaches for different purposes, and that the group which preferred scenic, natural beaches tended to be older and more educated." 9 refs.

Critical Comments

The evidence of more than one distinct subgroup is food for thought regarding generalized "public preferences." Only 8 photographs were employed.

Rabinowitz, C. B., and R. E. Coughlin.

1970. Analysis of landscape characteristics relevant to preference. Reg. Sci. Res. Inst. Discuss. Pap. Ser., Number 38. 88 p. Reg. Sci. Res. Inst., Phila., Pa.

Abstract

Attempts to identify specific objective characteristics of landscapes which are significantly related to preference ratings. Data on pollution, channel enlargement, and 183 site variables were gathered. Observers were then taken to the sites and asked for brief written descriptions and ratings of the sites on 29 different preference scales. A 17 x 23 descriptive matrix rating the characteristics of photographs of the areas was also developed.

Results indicate that people tend to agree more about what they like than about what they dislike. Preferred landscapes tended to be "park-like" or obviously man-influenced. Pattern and arrangement seemed to be important characteristics of preferred areas, while individual elements (primarily manmade, e.g., trash) were the focus of dislike. Although field observers and slide observers expressed the same scenic preferences, the important characteristics of those scenes differed between the groups. Preferences were highly correlated with attractiveness ratings. No refs.

Critical Comments

Authors note that preference for "park-like" landscapes may be influenced by the tendency for judges to think primarily in terms of recreation preference. It also may be an artifact of the particular landscapes employed.

Rabinowitz, C. B., and R. E. Coughlin.

1971. Some experiments in quantitative measurement of landscape quality. Reg. Sci. Res. Inst. Discuss. Pap. Ser. Number 43. 58 p. Reg. Sci. Res. Inst., Phila., Pa.

Abstract

The outcomes of several methods of evaluating scenic areas are compared: (1) housewives rated landscapes in the field using questionnaires, semantic differentials, and 14 rating scales (1-5). Six weeks later they rated slides of the same areas. (2) A community-action group rated slides of the same 14 stream sites used in experiment 1. (3) Housewives rated the slides in their homes.

Results showed substantial agreement among subjects and among experiments. However, landscape features that appear important on site differ somewhat from those identified in pictures. Different areas are preferred for esthetics than for use. No refs.

Critical Comments

May indicate a need to separate use-preference from esthetic-preference and to validate conclusions from slides by onsite comparisons. See related research by Rabinowitz and Coughlin (1970, p. 21) and Coughlin and Goldstein (1970, p. 14).

Randall, Alan, Berry Ives, and Clyde Eastman.

1974a. Bidding game for valuation of esthetic environmental improvements. J. Environ. Econ. & Manage. 1(3):132-149.

Abstract

An empirical case study of the benefits of abatement of esthetic environmental damage associated with the Four Corners power plant and Navajo mine using the bidding game technique is presented. Bidding games were carefully designed to avoid the potential problems inherent in that technique. The results indicate the existence of substantial benefits from abatement of this esthetic environmental damage. Aggregate bid curves, marginal bid curves, and estimates of the income elasticity of bid are presented. The effectiveness of the bidding game technique is discussed. 18 refs.

Critical Comments

Bidding game theory provides a promising approach to the difficult problem of scenic assessment and may find extensive use in the future. This article is a good introduction to bidding game procedures.

Randall, Allan, Berry C. Ives, and Clyde Eastman.

1974b. Benefits of abating esthetic environmental damage from the four corners power plant. Agric. Exp. Stn. Bull. 618, 40 p. N. M. State Univ., Las Cruces.

Abstract

This study was part of a larger, economic study concerning the Four Corners electric power-generation industry. Bidding game theory was used to derive... "monetary estimates of the benefits from abating the aesthetic environmental damage associated with the industry, as perceived by users of the affected environment." One conclusion was a confirmation of commonly held notion that environmental quality is a superior economic good.

Critical Comments

This is a well organized, well written report. Bidding game techniques are likely to play an increasing role in environmental evaluations and this paper provides a good introduction, by way of theory application to a relevant problem, to the procedures involved.

Rutherford, William, Jr., and Elwood L. Shafer, Jr.

1969. Selection cuts increased natural beauty in two Adirondack forest stands. J. For. 67(6):415-419.

Abstract

Five groups (Natural Beauty Conference members, College Forestry Club, high school biology teachers, college students, and silviculturists) were asked to evaluate 16 pairs of color slides by selecting the "most attractive" picture in each set. Each pairing included one slide which represented an undisturbed forest stand; the other represented a "stand that had been selectively cut 10 years ago." For softwoods, cut rather than uncut stands were preferred. However, for hardwoods cut and uncut stands were found equally attractive. 4 refs.

Critical Comments

The authors point out that what they measured was the relative attractiveness of paired slides—an ordinal measure of preference. They indicate the need to validate the study with actual field tests, and to extend the scenic preference procedure to all four seasons of the year. Photographers "composed" the slides used in this study, possibly introducing bias. Also, 17 percent of the responses were "undecided." These were excluded from the analysis, but there may be some valuable information therein.

Scherer, Ursula, and Robert E. Coughlin.

1971. The influence of water quality in the evaluation of stream sites. *Reg. Sci. Res. Inst. Work. Pap.*, 100 p. *Reg. Sci. Res. Inst.*, Phila., Pa.

Abstract

"Twelve subjects were taken to 12 stream sites varying in water quality, but generally similar in other respects. The subjects included eleven females and one male; all were adult, white, middle-class suburban residents. The subjects recorded, in response to questionnaires, their liking or disliking of the area, and their perceptions of aspects of the areas such as water quality and suitability for park development. Personal background information was also obtained from the respondents. The streams were rated by three trained observers for visual signs of pollution, and water samples were analyzed.

Results showed that respondents did recognize pollution, but that they did not take it into account when expressing their preferences for the stream sites. Water pollution did have an effect on perceived suitability of areas for water-related activities (wading, fishing), but not for non-water-related activities (relaxing, enjoying the scenery, picnicking)." No refs.

Scherer, Ursula, and Robert E. Coughlin.

1972. A pilot household survey of perception and use of a large park. *Reg. Sci. Res. Inst. Discuss. Pap. Ser. Number 59*, 51 p. *Reg. Sci. Res. Inst.*, Phila., Pa.

Abstract

A questionnaire was distributed to residents living around a 1294 acre park. The survey asked for evaluations of various characteristics of the park, indications of park use, and socioeconomic characteristics of the respondents. 31 refs.

Headings

Perception of the quality of the park; Relationship between perceptions of quality and other variables; Conceptualization of role and importance of the park; Relationships between role of the park and other variables; Effect of park on property value; Importance of park to choice of residential location; Actual property values.

Sewell, W. R. Derrick.

1971. Environmental perceptions and attitudes of engineers and public health officials. *Environ. and Behav.* 3:23-59.

Abstract

Presents two studies concerning experts' perceptions of the problems of environmental quality and the solutions which they recommend. Thirty engineers and 40 public health officials in British Columbia were interviewed. Open-ended and forced-choice questions were used. In some cases, questionnaires were left with the respondents. Factor analysis isolated 21 variables from the response lists. Results suggest three changes need to be made: (1) environmental problems should be viewed holistically (e.g., water pollution should not be isolated from air and land pollution), (2) the public should be involved in planning, and (3) administrative structures, laws, and policies should take a broader view. 31 refs.

Sewell, W. R. Derrick.

1974. Perceptions, attitudes and public participation in countryside management in Scotland. *J. Environ. Manage.* 2(3): 235-257.

Abstract

"This paper reviews evidence presented to the committee (Select Committee on Scottish Affairs) as to perceptions of various groups of appropriate uses of the Scottish countryside, and attitudes as to the appropriate note (sic) of the public policy-making. It describes two experiments in public participation undertaken in North America and offers a number of suggestions of studies that might be carried out to determine possible improvements in the public consultation process in Scotland."

One study on water quality in Denver brought together individuals from over 100 interest groups. Using an open response format, participants evaluated four water quality objectives submitted by the study staff.

The other study employed various techniques to obtain inputs from the public at each phase of the planning process: questionnaires, content analysis of news media, workshops, public meetings, public hearings, and referenda. Different techniques seemed to be more effective at some stages than at others.

Author concludes that more accurate measures of public preference and better planner-manager communications are needed. 39 refs.

Sewell, W. R. Derrick, and B. R. Little.

1973. Specialists, laymen, and the process of environmental appraisal. *Reg. Stud.* 7:161-171.

Abstract

"This paper examines one critical factor, specialization, and indicates the role it can play in undermining the presumed objectivity of appraisals. A conceptual framework for looking at the appraisal process as a socially legitimated form of environmental construing is set forth, and links with the environmental perception literature made. Several new methods for assessing 'psychospecialization' variables are outlined, together with a summary of some preliminary empirical studies." 31 refs.

Shafer, Elwood L., and Hubert D. Burke.

1965. Preferences for outdoor recreation facilities in four state parks. *J. For.* 63(7):512-518.

Abstract

"Personal interviews were conducted on four state parks in northeastern Pennsylvania to measure the direction and amount of the demand for outdoor recreation facilities such as swimming beaches, picnic areas, fireplaces, sanitation facilities, campsite spacing, and camping facilities. A photo-choice method that included a value assessment (1¢ to \$4.50) for the specific choice was used in the survey. Preference patterns were found to be consistent for the various facilities, so similar choices could be expected in comparable recreational situations. On both weekdays and weekends, campers differed significantly from noncampers in their preference patterns for swimming areas, fireplaces, camping facilities, and campsite spacings." No refs.

Critical Comments

Costs were too low to develop demand functions. Costs and facilities were confounded so that preferences for each cannot be identified, i.e., preferences are given for a particular facility at a particular price.

Shafer, Elwood L., Jr., John F. Hamilton, Jr., and Elizabeth Schmidt.

1969. Natural landscape preferences: A predictive model. *J. Leisure Res.* 1(1):1-19.

Abstract

An analysis of the public preferences for landscapes is made by having randomly selected Adirondack campers rate, on a 5-point scale, a randomized packet of 20 professional photographs. A total of 100 photographs which are "representative views of typical wildlands in the U.S.—excluding seashore scenes" are rated by respondents until there are 50 rankings for each picture. The results of the rankings are used as the data base in developing a mathematical model correlated with 46 variables identified by the authors as factors which comprise landscape descriptions. Using factor analysis and multiple regression, a 6 variable equation is developed. When field tested with a new set of pictures, the mathematical model accounted for 66 percent of the preference scores for photographs of landscapes. Possible application of the model to management and planning studies are explained. Appropriate discussion of possible modification of procedures reflecting potential impact of various management strategies is also considered. 4 refs.

Critical Comments

Comments by E. Gordon West. *J. Leisure Res.* 1(2):195. 1969. 1. The use of professional photographs biases the study, for a professional photographer seeks to interpret landscapes through his selection of scenes. 2. Black and white photographs decrease significantly the esthetic appeal of some landscapes, e.g., the Painted Desert of Arizona. 3. "The submission that their method 'can be used to help evaluate and compare the aesthetic quality of different landscapes' is highly questionable," without comparison of preferences for the photograph and the actual landscape.

Shafer's reply, *J. Leisure Res.* 1(2):197-198, 1969. 1. The 100 photographs were taken by many different photographers—in effect drawing our sample of 100 photos from an infinitely large number of photographer-scene combinations. 2. Black and white photographs were used to minimize costs. It is hoped that someone will replicate the study using color as an additional variable. 3. An onsite comparison of "preferences for scenes with preferences for photographs of the same scenes... would be very useful in aesthetic research."

Additional Comments

The variables selected for the factor analysis were generated from measurements of areas, perimeters, etc., on the photographs themselves, which may overemphasize photographic rather than physical site variables. Even if photographic sampling is valid (and there are indications that it is), such variables may not be the determinants of landscape preferences of onsite viewers.

Headings

Measurement of landscape variables; Landscape zone descriptions; Landscape zone dimensions; Tonal variables; Interview procedures; Model formulation; The data analysis model; Field test procedures; Methodology; Discussion of results; Strength of the model; Weakness of the model; Application of the model.

Shafer, Elwood L., Jr., and James Mietz.

1970. It seems possible to quantify scenic beauty in photographs. USDA For. Ser. Res. Pap. NE-162, 12 p. Northeast For. Exp. Stn., Upper Darby, Pa.

Abstract

The mathematical model developed by Shafer and others for the Northeast that modeled the scenic component of landscapes is field tested in the West (Wasatch National Forest near Salt Lake City). Fourteen photos were randomly chosen from the original 100 photos used in the development of the model. These photos were shown to residents of Salt Lake City who were day users in the Wasatch National Forest. The photographs were

divided into two packets of seven each. Each respondent was asked to rank the landscapes from 1 to 7 in order of preference. Every photograph was rated 50 times, thus its scenic quantified rating ranged from 50 to 350. The respondents' ratings of photographic landscape preference were compared to that predicted by the variables in the model. Respondent ratings were generally within one rank unit. 4 refs.

Critical Comments

The predictability of the model might be tested against photographs not used in the development of the model to show that the variables identified by the model are universal in affecting photo landscape preference. Landscape preference also should be field tested.

Shafer, Elwood L., Jr., and George Moeller.

1971. Predicting quantitative and qualitative values of recreation participation. *In* Recreation Symposium Proceedings. p. 5-22. U.S. Dep. Agric. For. Serv. Northeast For. Exp. Stn., Upper Darby, Pa.

Abstract

"Management and research responsibilities for meeting recreation demand are discussed, and proved methods for forecasting recreation use and associated qualitative values are presented. The best approach for developing recreation-participation rate equations may be to include a distance factor, recreation-supply variables, socio-economic measurements of users and non-users, qualitative measures of recreation environments—all in the same model. The effects of technological progress on values and behavior patterns are described, and methods for forecasting relevant technological advances are outlined." 47 refs.

Critical Comments

Authors recognize that scenic quality is only one variable affecting site use and propose a model that treats all the use variables.

Shafer, Elwood L., Jr., and Thomas A. Richards.

1974. A comparison of viewer reactions to outdoor scenes and photographs of those scenes. USDA For. Serv. Res. Pap. NE-302, 26 p. Northeast For. Exp. Stn., Upper Darby, Pa.

Abstract

"A color-slide projection or photograph can be used to determine reactions to an actual scene if the presentation adequately includes most of the elements in the scene. Eight kinds of scenes were subjected to three different types of presentation: (A) viewing the actual scenes, (B) viewing color slides of the scenes, and (C) viewing color photographs of the scenes. For each scene, responses to each of the three treatments were compared statistically and graphically." 7 refs.

Critical Comments

Authors found that, with reasonable caveats, color-slides or pictures can adequately represent landscapes; in this regard, see further empirical evidence presented in Daniel and Boster (1976, see p. 15).

Scenes included factories, junkyards, railroad tracks, etc. Only two scenes were not dominated by manmade elements. However, this technique may be applicable to less variable scenes, e.g., natural landscapes, though less complex methods (e.g., ratings on a single scale of scenic beauty) may differentiate between scenes as well. Study is similar to that of Zube et al. (1974, see p. 26).

The professional layout of this publication shows that research results can be presented in a highly readable manner.

Shafer, Elwood L., Jr., and Roger C. Thompson.

1968. Models that describe use of Adirondack campgrounds. *For. Sci.* 14(4):383-391.

Abstract

Mathematic models are developed to study "the relationship between camper use and 40 site characteristics of 24 Adirondack campgrounds. Factor analysis identified nine factors that conveyed all the essential information in the original set of 40 site variables. Regression analysis related average annual visitor-days per campground to factors containing campground size and associated water-recreation variables." Esthetic and other non-monetary values are implicit in the model and are partially determined through an analysis of the multiple regression predictive equation generated in the study. 7 refs.

Critical Comments

Esthetics may play only a minor role in determining camper use; visitor days depended almost entirely on the number of camp-sites ($r = .97$). This method could be used as a means of assessing its contribution, though in this particular study esthetic characteristics were not separated from physical site characteristics. Models of this type measure actual behaviors instead of what people say they will do.

Shafer, Elwood L., and Michael Tooby.

1973. Landscape preferences: An international replication. *J. Leisure Res.* 5(3):60-65.

Abstract

The mathematical model developed by Shafer et al. (1969) was field tested in Scotland. Campers evaluated the original 100 black and white photographs used to determine the six variable prediction equation on a scale of 1 to 5 packets of 20 pictures per respondent. The results support the reliability of the landscape preference prediction equation. It was hypothesized that "a photograph probably can measure on-site preference for a given landscape, if the photographic presentation contains most of the visual variation found in the actual landscape." 2 refs.

Critical Comments

Correlation studies between photographic landscape preference and actual landscape preference could validate the usefulness of the procedure and test this hypothesis.

Sinden, J. A.

1973. Utility analysis in the valuation of extra-market benefits with particular reference to water-based recreation. WRR1-17, 124 p. Water Resour. Inst., Oreg. State Univ., Corvallis, and Water Resour. Res. Cent., Univ. of Mass., Amherst.

Abstract

"... a photo-choice game to obtain cardinal estimates of preference or taste was developed from the theory of consumer choice. Taste was measured as willingness to pay extra fees and extra hours of travel. ... Demand functions were calculated for ten recreation activities. These functions were used to validate estimates of preferences. Participation in the activities was responsive to both distance—as a proxy for price—and to utility. But it was more responsive to taste. This result suggested the need to modify the traditional travel-cost procedure for valuing recreational benefits." 48 refs.

Headings

Benefit evaluation in principle and in practice; A general economic framework; Data collection; Derivation of demand

curves with the travel cost method; Indifference mapping for benefit values; Valuing option demand.

Sinden, J. A.

1974. A utility approach to the valuation of recreational and aesthetic experiences. *J. Agric. Econ.* 56(1):61-72.

Abstract

A method for valuing extramarket benefits is proposed and tested. The method rests on the empirical derivation of utility functions and indifference maps. Demand schedules were obtained from the indifference maps to provide specific benefit values. The method is compared to the conventional travel-cost method for valuing recreational benefits. It is argued that the utility approach is conceptually superior. Also, the utility data comprises both the benefit values from the indifference maps and direct survey responses as surrogates for utility. These data proved better predictors of consumption than the usual travel-cost variables. 11 refs.

Singh, Raghu N., and Kenneth P. Wilkinson.

1974. On the measurement of environmental impacts of public projects from a sociological perspective. *Water Resour. Bull.* 10(3):415-425.

Abstract

"... In an attempt to bring some empirical focus into this field [environmental impact measurement from sociological perspectives], attitudinal measures were employed to discover how residents of a river basin perceived negative and positive environmental impacts of a proposed watershed development project. ... Data on 343 heads of household in the selected areas [Texas] were collected through structured questionnaires with items on personal information, a vested interest scale, knowledge of the project scale, and an environmental impact scale. Data show that perception of impacts by residents is influenced significantly by degree of their vested interests involved. Variables for inclusion in a sociological model of environmental impact are suggested." 45 refs.

Critical Comments

That public perceptions should be considered when determining environmental impacts is a good point. Measurement of perceived impacts of completed projects might be more enlightening, especially if perceived impacts were related to the usual physical measures of impacts.

Sonnenfeld, Joseph.

1966. Variable values in space and landscape: An inquiry into the nature of environmental necessity. *J. Soc. Issues* 22(4): 71-82.

Abstract

Using paired comparisons of colored slides, various groups of respondents (Eskimos, Alaskan non-natives, high school and college students) indicated environmental preferences for living, camping, or visiting. Preliminary results suggest: (1) landscape and space represent different environmental experiences, (2) populations differ in environmental perceptions, (3) adjustment and adaptation efforts to improve landscape quality for natives may be wasted, (6) non-natives may never be satisfied, (7) the real problems of the future environment are ecological.

Critical Comments

This is a good discussion of adaptation. Man may indeed adapt to declining landscape quality; whether he should be required to do so is a value question.

Sonnenfeld, Joseph.

1967. Environmental perception and adaptation level in the Arctic. *In* Environmental perception and behavior. p. 42-59. David Lowenthal, ed. Dep. of Geogr., Res. Pap. 109. Univ. of Chic., Ill.

Abstract

Harry Helson's Adaptation-Level Theory (1964) is suggested as an explanation for the varying environmental perceptions among northern Alaskan populations. The methodology of the Arctic study consisted of a questionnaire, a semantic differential test, and a photo slide test. Subjects were shown pairs of slides which depicted "one or more of the four basic dimensions—topography, water, vegetation, and temperature" in various landscape settings. Each subject was to select the landscape he preferred. A quantitative landscape scale was established by three judges who rated each picture on the four dimensions using a scale of 1 to 3 for each dimension. Choice differences due to sex, age, native/non-native, location in Alaska (variation among villages) and in Alaska versus Delaware (see following abstract), and previous environmental experiences are reported. Results suggest that landscape preferences change as one experiences new environments. 3 refs.

Sonnenfeld, Joseph.

1969. Equivalence and distortion of the perceptual environment. *Environ. and Behav.* 1:83-99.

Abstract

A semantic differential technique (based on Osgood et al. 1957) was devised to determine "what it is that constitutes the environment to which a population is sensitive. Concept variables provide the focus, and in this test represent the environmental elements that are being analyzed for the different meanings they have for different populations. . . Physical concepts. . . included. . . snow, rain, fog, wind, sunshine, night, clouds, summer, winter, spring, fall, moon, sun, and northern lights." Twenty-five bipolar scales (e.g., like-dislike, hot-cold, etc.) were used to define the physical concepts [on a five-point bipolar scale (-2,-1,0,1,2)]. An analysis of scales grouped into the functional categories of adjustment factor, attractiveness factor, and wilderness factor was performed. Based on the results of numerous tests of several population samples, "an 'environmental personality type' is postulated that will be found among all populations, regardless of the contrast in cultural values otherwise distinguished between them, and regardless of the contrasts in environments they occupy." Work is also reported on a personality inventory. "Environmental personality may prove the key to between-population similarity in environmental behaviors even as it provides a basis for understanding within-population differences in these behaviors." 3 refs.

Stankey, George H.

1972a. A strategy for the definition and management of wilderness quality. *In* John V. Krutilla, ed., *Natural environments: Studies in theoretical and applied analysis*. p. 88-114. Johns Hopkins Univ. Press, Baltimore, Md.

Abstract

A questionnaire was employed to examine four parameters of wilderness use: intensity of use, character of encounters, spatial-temporal aspects, and destructive visitor behaviors. An effort is made to determine how use effects visitor satisfaction and how purist attitudes should effect wilderness management. No refs.

Critical Comments

Contains an excellent discussion of wilderness carrying capacity.

Stankey, George H.

1972b. The use of content analysis in resource decision making. *J. For.* 70(3):148-151.

Abstract

Content analysis is a procedure designed to "record and describe the content of communications such as letters, newspaper articles," or questionnaires. It consists of four steps: (a) selection of response categories, (b) sampling, (c) measurement, (d) analysis. Problems and procedures of content analyses are illustrated by a 1969 analysis of a [National Forest] questionnaire dealing with different recreation development strategies for the Mission Mountain Primitive Area. [The] Coding of responses, cross-classification of variables, and ability to evaluate large numbers of communications are discussed. 6 refs.

Critical Comments

Procedure provides a somewhat objective means to analyzing unstructured verbal inputs. However, coding is time consuming and depends on coders' perceptions.

University of Newcastle Upon Tyne.

1971. Landscape reclamation. p. 127-135. IPC Sci. and Tech. Press Ltd., Surrey, Eng.

Abstract

Referenced pages (chapter 13) present a visual assessment of reclaimed landscape based on the work of J. J. Ffennell and others. 11 refs.

Selected Headings

Appreciation of landscape; Method of analysis; Government policy towards the environment of the North East; Visual results of landscape reclamation; Questionnaire on visual analysis; Attitudes to the site before reclamation, — during reclamation, — since reclamation; Suggestions for improvement; Questionnaire—as environmental quality indices.

Wenger, Wiley D., Jr., and Richard Videbeck.

1969. Eye pupillary measurement of aesthetic responses to forest scenes. *J. Leisure Res.* 1(2):149-161.

Abstract

"The relationship between eye pupillary responses and aesthetic reactions to forest scenes was explored. The objective was to find an improved method for revealing the direction and degree of emotional response in landscape aesthetics research. It was predicted from Hess's affect hypothesis that campers dilate more to landscapes than do non-campers and that females dilate more than males. Analyses of variance of 32 subjects' responses to 25 landscape slides revealed reliable differences between campers and non-campers, though the direction of the differences was opposite to predictions. On the basis of the findings, the authors speculate that an information-processing hypothesis may account for observed pupillary responses better than Hess' affect hypothesis. It was concluded that pupillary measures are useful in exploring new facets of aesthetic responses, but that another autonomic measure might be as useful without having as many inherent technical and physiological problems." 23 refs.

Critical Comments

There is evidence suggesting that campers and noncampers may share the same landscape preferences. But the reliable differences between campers and noncampers in a direction opposite of that predicted by the author may suggest that some sort of adaptation of interest factor may be playing a role. Effort to obtain a reliable physiological measure of preference is commendable.

Wohlwill, Joachim F.

1968. Amount of stimulus exploration and preference as differential functions of stimulus complexity. *Percep. and Psychophys.* 4:307-312.

Abstract

"Two sets of photographic slides, one made up of scenes from the geographic environment, the other of works of nonrepresentational modern art, were scaled for complexity by obtaining judges' ratings of amount of variation presented on several specified stimulus attributes. Fourteen slides defining a seven-point scale of complexity were selected from each set and given (sic) to college students to obtain measures of (a) amount of exploratory behavior (number of times S chose to expose each slide briefly), and (b) preference (evaluative ratings on a seven-point scale). In accordance with prediction, the former measure emerged as a linearly increasing function of complexity, while the relationship between complexity and preference was curvilinear, reaching a maximum at an intermediate level of complexity. The results are related to Berlyne's distinction between specific and diversive stimulus exploration, and implications for the study of aesthetics are discussed." 15 refs.

Critical Comments

The effort to validate complexity as an important determinant of landscape esthetics is commendable in that complexity is often included in intuitive models. See Kaplan, Kaplan, and Wendt (1972, p. 18) for a follow-up study.

Zube, Ervin H.

1973a. Scenery as a natural resource: Implications of public policy and problems of definition, description, and evaluation. *Landscape Archit.* 63(2):126-132.

Abstract

The state of the art in evaluating scenery as a natural resource is discussed. Several procedures developed in the later 60's and early 70's are noted and the need to incorporate more communicability, credibility, and predictability into scenic assessment procedures is emphasized. The need to develop improved techniques that "identify those aspects of scenery which mean something to the broadest range of people. . . and evaluative scales that are stable enough to influence a wide range of decisions when we allocate the resources that make a scene" are the keys to giving the scenic component of resources fair consideration in planning and management implementation of natural resources. No refs.

Zube, Ervin H.

1973b. Rating everyday rural landscapes of the Northeastern U.S. *Landscape Archit.* 63(4):371-375.

Abstract

Attempts to assess the degree of agreement between different groups of people on the evaluation of slides of rural landscapes. Nine of 27 slides were drawings that could be manipulated. Real world slides were selected for systematic variation on some variables. Participants were asked to select the slide with the highest scenic value from slide pairs and to describe 4 slides using 14 semantic scales.

The results revealed substantial evaluative agreement between groups of designers, resource managers and technicians, students, housewives, teachers, and secretaries. In most groups responses to real world slides differed from the responses to drawings. Scenic value seems to increase with increasing land use diversity. No refs.

Zube, Ervin H.

1974. Cross-disciplinary and intermode agreement on the description and evaluation of landscape resources. *Environ. and Behav.* 6:69-89.

Abstract

A study of the similarities and differences of two modes of landscape analysis, (1) field reconnaissance and (2) office study using aerial photographs and topographic maps, and two distinct professional populations of evaluators, environmental designers and resource managers. Landscapes were described and evaluated by: (1) 25 semantic scales, (2) unstructured descriptions, (3) rank ordering by scenic quality.

"Both the factor analysis of the semantic scale data and the rank ordering of the aerial photographs indicate meaningful levels of agreement between groups on evaluation regardless of mode of analysis. . . There is reason to believe, therefore, that communication about scenic resources is possible in meaningful terms without resort to a pseudo-professional jargon and without the invocation of an aesthetic elitism." Some "potentially important" methodological differences were noted, however; "field analysts" focus on materials and objects, while "office analysts" focus on the spatial distribution of these materials and objects. 21 refs.

Critical Comments

The tendency of office analysis to focus on spatial distribution may be a function of the aerial photographic presentations. Would eye level photos, simulating the experiences of field analysts, produce the same results?

Zube, Ervin H., David G. Pitt, and Thomas W. Anderson.

1974. Perception and measurement of scenic resources in the Southern Connecticut River Valley. *Inst. Man and His Environ.* Publ. Number R-74-1, 191 p., *Inst. Man and His Environ.* Amherst, Mass.

Abstract

Thirteen groups of professional and nonprofessional participants were asked to evaluate and describe 8 landscapes by using a 51-feature check list and 18 semantic scales. Some subjects evaluated the sites in the field, while others viewed panoramic photographs of the site. All participants also rank ordered, according to scenic quality, the 8 views and sorted 56 other color photos into 7 piles representing 7 levels of scenic quality. The authors then analyzed all areas on 23 quantifiable dimensions. Analyses of the findings revealed a high correlation between the evaluations of field observers and photograph observers. Generally impressive levels of agreement were found among the thirteen subgroups on all measures of landscape quality (with the possible exception of inner-city residents). Six landscape dimensions accounted for 51.4 percent of the variance. 44 refs.

Critical Comments

Very thorough presentation of an extremely comprehensive study, though it could be better organized. Some very interesting conclusions often running counter to intuitive expectations are presented. The semantic scales tend to give little information, however. Preferred environments tend to be described in terms of positive weightings on the semantic scales, e.g., beautiful (vs. ugly), inviting, like, tidy, etc. Such descriptors may be redundant of preference.

MISCELLANEOUS

This section includes papers taking a variety of viewpoints and approaches. Some are economic analyses or computer mapping techniques. Others focus on the scenic beauty of highway environments. Still others are suggestions for research strategies, but offer no specific techniques.

Benson, Robert D.

1974. Lodgepole pine logging residues: Management alternatives. USDA For. Serv. Res. Pap. INT-160, 28 p. Intermt. For. and Range Exp. Stn., Odgen, Utah.

Abstract

"The dollar and nondollar effects of alternative levels of residue utilization in mature lodgepole pine are compared. Net dollar returns were greater in conventional logging (removal of green sawlogs to a 6-inch top with slash piled and burned) than in near complete harvesting (sawlog removal followed by field chipping of remaining wood material on the site). However, substantial nondollar benefits were gained by near complete harvesting, especially in esthetics, full reduction, and site preparation. Continuing studies of harvesting influences upon soil, hydrology, nutrients, and regeneration will further define costs and benefits, and will provide managers with guidelines for harvesting practice decisions." 9 refs.

Critical Comments

Esthetic evaluations were made by using the Daniel et al. (1973) quantification method and by expert judgment. Author notes that "nondollar values expressed along a utility index from 0 to 100 do not necessarily have equal importance. On a given situation, for example, the wildlife considerations may overshadow any of the other nondollar (or dollar!) values involved. When this happens, quantitative analysis must stop and the judgment of the land manager must take over."

Headings

Net dollar values; Esthetic evaluation; Wildlife evaluation; Preliminary regeneration evaluation; Fuels, fire hazards, and burning; Hydrology, soil, and nutrients; Utilization of residues.

Clay, Grady.

1965. The woodland scene: Time for another look. *Landscape Archit.* 56(1):28-29.

Abstract

A short discussion of "good scenery" and its relationship to certain management practices (e.g., sustained yield). Past management practices of passive protection by the National Park Service are discussed. The need to focus on landscape use—implying an analysis of visual composition, balance, harmony, unity, and contrast of form, identified by Twiss and Litton (1966)—in management practices is emphasized. 4 refs.

Critical Comments

Visual composition variables—balance, harmony, unity, contrast, color, texture—may pose problems for nonlandscape architects unfamiliar and untrained in their use.

Cox, P. Thomas, Adrain L. Haught, and Ervin H. Zube.

1972. Visual quality considerations in regional land use changes. *Growth & Change*, Apr.:9-15.

Abstract

This paper discusses a method of incorporating environmental concerns, e.g., visual quality, into a multiobjective planning framework. The study area was the North Atlantic Region including the James River Basin (Virginia) and all or parts of thirteen northward states which drain into the Atlantic. The area was first inventoried according to a system that distinguished land form and landscape pattern. Using criteria based on diversity of land use and three-dimensional contrasts of the land form, the landscapes were then evaluated by consulting landscape architects. Two linear programming runs (the objective function was to minimize total costs), one with and one without the visual quality constraints, provided quantitative estimates of the differences in costs between obtaining the visual quality objective and obtaining the economic efficiency objective. The output included land use distribution changes under the visual quality constraints. Further research into the tradeoffs inherent in multiobjective planning is suggested. 7 refs.

Critical Comments

A sound, if preliminary, approach to assessing the costs of providing visual quality vs. economic efficiency. The visual quality rating system used was crude (3 levels—high, medial, low—judged by architectural consultants). Management costs were clearly higher when visual constraints were added.

Davidson, Paul.

1967. An exploratory study to identify and measure the benefits derived from the scenic enhancement of federal-aid highways. *Highw. Res. Rec.* 182:18-21.

Abstract

The study focuses on the benefits of scenic enhancement of highways for pleasure driving. A multiregression analysis (based on an independent and earlier household survey) was performed to isolate "significant variables that influence the desire to engage in pleasure driving." Conclusions based on income, age, sex, race, and location are reported. Only direct engineering costs along the roadway are discussed and scenic components of highway environments are not identified. No refs.

Critical Comments

While the variables may be correlated with the occurrence of driving pleasure, they may not indicate the desire to do so.

Elsner, Gary H.

1971. Computing visible areas from proposed recreation developments. . . a case study. USDA For. Serv., Res. Note PSW-246, 10 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Abstract

"A new computerized technique called VIEWIT for measuring the terrain visible from a given point was applied in a study on the Black Hills National Forest, South Dakota. The seen area from 12 heavily visited scenic points and along three proposed routes for a scenic tramway were delineated. The computer produced overlay maps that show the maximum area visible from each observation point." 2 refs.

Ferris, Kimball H., and Julius Gy. Fabos.

1974. The utility of computers in landscape planning: The selection and application of a computer mapping and assessment system for the Metropolitan Landscape Planning Model (METLAND). *Mass. Agric. Exp. Stn. Res. Bull.* Number 617, 116 p. Coll. Food and Nat. Resour., Univ. Mass., Amherst.

Abstract

"This study was undertaken to select a computer manipulating and mapping system to improve the existing technique. . . The initial landscape resource assessment portion of the study was designed to evaluate available earth resource and land use data. . . An isopleth mapping procedure was employed to assess the geographic distribution of the resource values and the magnitude of resource value change. . . ." 57 refs.

Headings

State of the art of geographic information systems; Selection of a digitizing system; Application of COMLUP; Comparison of analysis techniques.

Fuhriman, Jerry W.

1973. An overview: The development of aesthetic opportunity criteria as it relates to the planning process. *In* *Toward a Technique for Quantifying Aesthetic Quality of Water Resources*, p. 22-31. Perry J. Brown, ed. PRWG-120-2. Utah State Univ., Logan.

Abstract

Esthetic quantifications systems should meet the following criteria: "a) The quantification system should provide a means for giving value to the relationship which exists between aesthetic opportunity and inherent quality. b) The quantification system should be developed in such a way as to give insight regarding aesthetic opportunity as it relates to a given broad scale region. c) The quantification system should be developed to achieve insight regarding to aesthetic opportunities that exist in relation to a given function and a specific landscape/waterscape. d) The quantification system should be readily adaptable to any planning methodology." Several studies (especially Murray et al. 1971) are discussed with reference to the four criteria. 5 refs.

Critical Comments

Criteria a, b, and c are stated in general terms only.

Headings

Current planning methods; Attractiveness vulnerability-impact; Leopold scheme: A digression.

Garthwaite, P. E.

1971. Forest management for conservation, landscaping, access, and sport. Res. and Dev. Pap. Number 81, 20 p. For. Comm., London.

Abstract

Presents a general discussion of the costs and benefits of landscape design. 10 refs.

Critical Comments

Notes that increasing scenic beauty may cost little in lost revenues from economic yields. What it *will* cost is more planning time.

Headings

The size and scope of the problem; Change in woodland area; Timber production; The changing landscape problems of forestry; The constraints; Achieving practical results in forest landscape design; Future trends.

Goodey, B., D. Donnelley, M. Menzies, and D. Spencer.

1973. The Teme Valley scenic route: An informal assessment. Work. Pap. Number 9, 20 p. Univ. of Birm., Eng.

Abstract

An informal, direct evaluation of the scenic route also studied by Dunn (1973, see p. 16).

Grodzik, R. M., H. E. Jackson, and A. E. Rattray.

1973. An evaluation of water landscapes. 129 p. Agassiz Cent. Water Stud. Univ. of Manit., Winnipeg, Can.

Abstract

Assesses the "GRID ANALYSIS" technique (computer-aided mapping) for resource evaluation and land use allocation. Site suitability for 12 land uses and sensitivity to 7 land use interventions are mapped. Values are determined by professional judgment based on physical site characteristics. 36 refs.

Hornbeck, P. L., R. R. Forster, and M. R. Dillingham.

1969. Highway aesthetics—functional criteria for planning and design. *Highw. Res. Rec.* 280:25-38.

Abstract

"This report examines the function and use of aesthetic criteria for the highway development process. . . The major premise established for procedure of the study is that 'aesthetics' is not an additive to the process of highway planning and design but must be identified and implemented as an integral component.

The research report identifies the visual parameters of the highway planning process related to a range of disciplines; evaluates them for their relevance to improved highway appearance and use, and driver behavior; suggests a methodology to identify and integrate visual and behavioral criteria for a more complete highway planning process; and applies this methodology in a demonstration case study." 3 refs.

Critical Comments

Visual analysis is in terms of the interaction of duration and incidence of five visual elements: edge, enclosure, objects' dominance, alinement, and diversity. Visual quality is treated as the ability of drivers to view the environment and the effects of the view on driver behavior. This is not the same as scenic quality (and is not meant to be).

Hornbeck, P. L., and Garland A. Okerlund.

1972. Visual quality for the highway user: A study of the relation of factors of visual quality to route design. *Highw. Res. Rec.* 410:52-63.

Abstract

According to the authors, "qualitative experience potentially available from the highway environment" is to be provided through highway alignments by allowing views of various durations. Four problems that summarize the visual and esthetic aspects of the driving experience are identified. A descriptive procedure for integrating these components into the planning process (through the use of inventory, guideline, and resolution maps) is suggested. Provincetown on Cape Cod is used as a sample site to illustrate the mapping technique. 26 refs.

Kates, Robert T.

1966. The pursuit of beauty. *Proc. Symp. Nat. Beauty*, p. 34-50. [Ohio State Univ., May 24, 1966.]

Abstract

The goals of environmental management consist of three fundamental factors: physical and mental health, sensory and participatory pleasure, and economic value. Beauty is demonstrated to be a constituent part of each of these factors. The management of public spaces through public involvement should be designed to decrease ugliness by identification of contextual environmental misfits. The hope for attaining beauty lies in the employment of experts who can provide access to the "rare and unique" experience of beauty. According to the author, experts are needed to inject beauty into the landscape or townscape by (1) identification and preservation of the beautiful and good that already exists; (2) provision of accessibility to existing but unseen beauty; (3) the design of landscape and townscape beauty. 11 refs.

Critical Comments

Certainly points 1 and 2 (above) can be determined by the public and the public can also have input into point 3. Kates' view of beauty is very restrictive and many will disagree that only experts can show the path.

Headings

Introduction; The new conservation; Beauty and the goals of environmental management; Beauty in nature and art: The artificial-natural dichotomy; Beauty and the private sector; The measurement of beauty—measuring ugliness, beauty, and interest; The provision of beauty; Conclusion: A public policy for beauty.

Johnson, Hugh A., and Jesse R. Russell.

1967. Economics of natural beauty. In Proc. 23rd Annu. Meet. Soil Conserv. Soc. Amer. p. 1-18. USDA Econ. Res. Serv., Wash. D.C. [Des Moines, Iowa, Aug. 13-16, 1967.]

Abstract

A national environmental ethic is needed to support efforts to incorporate and maintain beautification concerns in resource planning and management. The costs and benefits of incorporating beauty in planning implementation are discussed and several examples of development outcomes are cited. 15 refs.

Headings

Beautification in resource planning; Beauty and a resource ethic; Economics in beauty; Beautification in action. [Summary and conclusions.]

Kojima, Michimasa, and J. Alan Wagar.

1972. Computer generated drawings of ground form and vegetation. J. For. 70(5):282-285.

Abstract

"Describes the application of two computer programs that generate perspective views of the landscape, permitting the visual effects of proposed landscape modifications. Perspective drawings of ground form are represented by a grid of distorted squares. . . by one program while the other program plots ". . . vegetation types, water and clearings as they would appear on the landscape." The location of the observer is flexible, allowing many different perspective views to be considered. 15 refs.

Critical Comments

The procedure is useful only for the experienced landscape planner who can mentally combine the simplified computer images with actual landscapes.

Lansing, John B., and Robert W. Marans.

1969. Evaluation of neighborhood quality. Amer. Inst. Plann. J. 35:195-199.

Abstract

"Efforts to improve neighborhood quality assume that planners can distinguish good from bad neighborhoods and can isolate specific features that are related to overall quality. In this study one hundred clusters of three or four homes scattered through a metropolitan area were rated independently by the people who live there and by an architect-planner. Results show considerable disagreement on the ratings, with people who attended college agreeing with the planner more closely than those with less education. The best single predictor of how well people like a neighborhood is the maintenance level of the structures as rated by the architect-planner." 7 refs.

Lucas, Robert C.

1966. The contribution of environmental research to wilderness policy decisions. J. Soc. Issues 22(4):116-126.

Abstract

The meaning and value of wilderness and the question of how a wilderness remains so if it is used is discussed. Definite management policies must be identified to support the concerns of the professional manager and the public wilderness user. Interdisciplinary environmental research techniques should be developed which identify the esthetic components that make landscapes pleasant or unpleasant and need to be integrated with planning, policy formulation, and management procedures. 16 refs.

Headings

Wilderness and wilderness use; The policy problems; The contribution of environmental research.

Menchik, Mark D.

1971. Residential environmental preferences and choice: Some preliminary empirical results relevant to urban form. Reg. Sci., Res. Inst. Discuss. Pap. Ser. Number 46, 93 p. Reg. Sci. Res. Inst., Phila., Pa.

Abstract

In order to evaluate people's demands for new forms of residential environments (such as cluster development rather than the spread pattern of suburban sprawl), it may be useful to deal with people's residential preferences directly, rather than with their market choice. The paper develops residential environmental preference variables from questionnaire survey data. The preferences may be thought of as relative tradeoffs among [the] residence accessibility, characteristics of the house and lot (e.g., lot size), [the] quality of the natural environment, and characteristics of the nonnatural environment (e.g., population density). At the same time, comparable measures are devised for the characteristics of the respondents' present residential choices. 26 refs.

Michelson, W.

1966. An empirical analysis of urban environmental preferences. J. Am. Inst. Plann. 32:355-360.

Abstract

Respondents were shown photographs of urban environments and asked to rank them for preference and give open ended evaluations. Then they were asked to describe their ideal of an urban environment, as well as their past experiences with urban settings. The relationship between social variables and physical environmental preferences is discussed. No refs.

Murison, W. F.

1965. Landscape forestry: A new profession. *Landscape Archit.* 56(1):30-31.

Abstract

Argues for a joint forestry profession that combines an economic orientation with that of a landscape architect, thereby managing forests with a simultaneous concern for economics and esthetics. The need for multiple use of forests is identified with special focus on high population density regions of the U.S., e.g., the Northeast. 4 refs.

Newby, Floyd L.

1973. Indicators for aesthetic opportunity. In *Toward a Technique for Quantifying Aesthetic Quality of Water Resources*, p. 76-87. Perry J. Brown, ed. PRWG-120-2. Utah State Univ., Logan.

Abstract

The author argues that esthetic opportunities must be determined from an analysis of human needs as they relate to environmental order and complexity. The development of planning models should focus on "defining organizational elements within an environment which alters behavior and then developing a predictive model to assess the direction of behavioral responses." Management policies based on social norms are viewed as constraints on some individual's optimum growth and self actualization. 8 refs.

Critical Comments

Discussion is based on unvalidated assumptions of man's psychological "needs," drawn from Maslow's personality theory. Some general recommendations for research are included, but no specific proposals for esthetic management are discussed.

Pearson, P. M., and W. A. McLaughlin.

1968. Toward design criteria for highway aesthetics. *Highw. Res. Rec.* 232:9-15.

Abstract

"A framework of investigations into design criteria which will not only include the traditional Newtonian Criteria but measurable aesthetic considerations from the driver's point of view is established. The driving task is developed as a system. The inputs are perceived by the driver, a value judgment is made and outputs are produced. The experimental method suggested deals with the value judgment. It is suggested that the driver's outputs are a reflection of his state of mind. The galvanic skin response and other apparatus are suggested to measure these outputs. By relating the state of mind or an acceptable level of risk to geometric elements, design criteria can be developed to allow the driver freedom to enjoy the beauty of the environment. Until this is accomplished, there is little logic in providing, at additional costs, so-called aesthetic qualities in design." 11 refs.

Critical Comments

E. H. Geissler and A. Aziz, Department of Highways, Ontario, Canada, suggest that the authors consider the following points in their design criteria: "a) the view the highway offers to the onlookers across the environment the highway passes through, b) the view of the driver across the environment as he travels along the roadway."

Author's Reply: "This paper was confined to the relationships between the driver and the structural and geometric elements of the roadway. We felt that until there is a feeling of

security on the part of the driver, there was no point in beautifying the roadway for his benefit. This was a stated constraint in that we did not consider the nondriving population."

Additional Comments

Authors recognized that tradeoffs may have to be made between service, safety, cost, and beauty and anticipated Geissler and Aziz's criticisms.

Peterson, George L.

1967. Complete value analysis: Highway beautification and environmental quality. *Highw. Res. Rec.* 182:9-17.

Abstract

A philosophical definition of esthetics is introduced as a measure by which one can identify beauty. Three reasons for including environmental beautification concerns in engineering projects are discussed within the context of economics and art. An equation that defines visual quality (beauty) as a function of "sound physical quality, harmony with nature and variety" is developed and presented as a way to assess the beauty of residential neighborhoods. General recommendations to incorporate esthetic concerns into the planning process include adding landscape architects, architects, designers, and the general public to the decision process. The "beauty" of billboards is also discussed. 12 refs.

Critical Comments

The "complete value analysis" referred to in the title is misleading because the analysis is probably incomplete. The analysis procedure is also value laden with the author's own preconceived esthetic standards.

Headings

Searching for a model; Highway beautification; Engineering; Economics and Art; Toward some specific answers; General recommendations; Billboards.

Schechter, M., and M. Barnea.

1973. The expenditures on nature and landscape. *J. Environ. Manage.* 1:393-404.

Abstract

"This investigation presents data on the scope of public resources allocated to nature and landscape conservation (NLC) in Israel during the years 1960-69. The activities of public bodies are estimated in terms of both absolute and relative levels of public funds allocated for this purpose. Comparisons are also made between Israel and several Western European countries. The main question arising out of the analysis is whether the allocations to NLC activities indeed reflect prevailing social preferences. The writers suggest that perhaps this is not the case, and offer several explanations for the apparent discrepancy." 9 refs.

Snow, W. Brewster (ed.).

1959. *The highway and the landscape.* 230 p. Rutgers Univ. Press, New Brunswick, N.J.

Abstract

Authors with diversified [but relevant] backgrounds comment in general terms on landscape design as related to highway design. No refs.

Headings

The complete highway (Spencer Miller, Jr.); The parkway idea (Gilmore D. Clarke); The challenge of the new highway pro-

gram (Charles A. Glover); They planned a suburb well (Jay Dugan); The art of fitting the highway to the landscape (F. W. Cron); Preserving the scenic qualities of the roadside (Wallace A. Johnson); Good highway design is economical (Oliver A. Deakin); The new highways and property values (Edward A. Sprague); Zoning for roadside protection (Erling D. Solberg); Politics and road building (Joseph C. Ingraham); The functional uses of plants on the complete highway (Richard P. White); Suggested plant materials (Richard P. White).

Tybout, Richard.

1966. The problem of collective choice in aesthetic matters. Proc., Symp. Nat. Beauty. p. 51-63. [Ohio State Univ., May 24, 1966.]

Abstract

Various approaches (based on previously developed economic techniques) are proposed to evaluate collective choices relating to esthetics as one component of planning and management decision-making. Sometimes esthetic considerations can be isolated as major decision factors, facilitating decision-making. When esthetics cannot be built into a decision structure, it should be given considerations by explicitly stating esthetic outcomes under various alternative plans. No refs.

Veal, A. J.

1973a. Notes on attraction, preference, and choice in recreation. Univ. Birm. Work. Pap. Number 5, 32 p. Univ. of Birm., Eng.

Abstract

Examines the possibility of studying preference and choice through a comprehensive study of leisure behavior and attitudes, and examines published research on site attraction (trip-distribution models) and questionnaire surveys.

Veal, A. J.

1973b. A discussion of the role of environmental perception in recreation planning, with particular reference to country parks, forests, and sports centres. Work. Pap. Number 10, 64 p. Univ. of Birm., Eng.

Abstract

Discusses further the comprehensive approach to recreation research as put forward in Working Paper 5 and explores the relevance of perception research in the three areas specified.

Wagar, J. Alan.

1964. The carrying capacity of wild lands for recreation. For. Sci. Monogr. 7, 24 p.

Abstract

"This study analyzes the carrying-capacity problems in terms of (1) the impact of the recreation environment on people, (2) the impact of people on the recreation environment, and (3) management procedures to modify these reciprocal impacts. . . It also evaluates the probable effects of crowding on satisfaction. . . Ecological considerations include an experiment in which recreational foot traffic was simulated on a series of vegetated plots." 22 refs.

Critical Comments

Insightful discussion of the problem, but no experimental support for discussion of objectives 1 and 3.

Waller, R. A.

1970. Environmental quality, its measurement and control. Reg. Stud. 4:177-191.

Abstract

"The paper summarizes techniques of (environmental quality) evaluation and puts forward a method by which many diverse aspects of the environment can be related to a common scale which in turn can have a monetary value attached to it. The implications of this philosophy are explored in the context of political decisions relating to planning problems and using traffic noise as an example demonstrates how cost-benefit techniques can be applied to environmental questions." 9 refs.

Warner, Maurice L., and Edward H. Preston.

1974. A review of environmental impact assessment methodologies. Socioeconomic Environ. Stud. Ser., EPA-80015-74-002, 27 p. Off. Res. and Dev., U.S. Environ. Prot. Agency, Wash. D.C.

Abstract

Seventeen tools or methodologies designed for or applicable to the preparation of environmental impact statements are reviewed to identify their strengths, weaknesses, and potential range of use. Specific criteria are suggested for evaluating the adequacy of an impact assessment methodology in terms of: impact identification, impact measurement, impact interpretation, impact communication, resource requirements, replicability, and flexibility.

The reviews presented serve as an introduction to the range of tools available and demonstrate that no single approach to impact assessment is superior in all circumstances. 17 refs.

Winkel, G. H., Roger Malek, and Philip Thiel.

1969. The role of personality differences in judgments of roadside quality. Environ. and Behav. 1:199-223.

Abstract

A study of the factors contributing to visual preferences for roadside development. An environmental "personality" scale was developed which included abstractions from Child's personality scale, attitudes about art, scanning-focusing scales, and statements related to environmental and design attitudes. In addition, 80 observers were asked to evaluate a set of slides of roadside environments using 64 semantic scales. Then they were shown the same slides with roadside artifacts (e.g., billboards) removed and asked to note differences and re-evaluate the slides on the semantic scales. Eye movement recorders were employed to note observers' fixation points.

Factor analysis revealed three factors in the personality scale. Two of the factors were correlated with the slide ratings. 18 refs.

Yi, Fu Tuan.

1967. Attitudes toward environment: Themes & approaches. In Environmental Perception and Behavior. p. 4-17. David Lowenthal, ed. Dep. of Geogr., Res. Pap. 109, Univ. Chic., Ill.

Abstract

This is a brief survey of man's historical attitudes toward the environment. The focus is on man's "world" (as distinct from man's "environment") as depicted in a selected review of historical literature. Man's world is considered from five viewpoints: (1) an individual's attitude toward a particular aspect of environment, (2) an individual's attitude toward a region, (3) an individual's conception of the man-nature synergism, (4) the attitude of people (or peoples) toward environment, and (5) native cosmographies. 46 refs.

Zube, Ervin H., Robert O. Brush, and Julius Gy. Fabos, eds.
1975. *Landscape assessment—values, perception, and resources.*
367 p. Dowden, Hutchinson, and Ross, Inc., Stroudsburg,
Pa.

Abstract

Contains articles relating to various aspects of landscape assessment: historic values, perceived values, and values based on landscape inventories. Most of the authors were participants in a conference on landscape assessment, Nov. 15 and 16, 1973 in Amherst, Massachusetts. 608 refs.

Critical Comments

Extensive bibliography is provided.

Headings

LANDSCAPE VALUES: The historic American landscape (John B. Jackson); Qualitative landscape values: The historical perspective (Roderick Nash); This fair land (Calvin W. Stillman); Qualitative values in the landscape (Garrett Eckbo); The economics of a view (Ross S. Whaley); Preservation policy and personal perception: A 200-million-acre misunderstanding (Charles E. Little). **LANDSCAPE PERCEPTIONS:** Problems of scale and context in assessing a generalized landscape for particular persons (Barrie B. Greenbie); An informal model for the prediction of preference (Stephen Kaplan); Aesthetic factors in visual evaluation (Ian C. Laurie); Some methods and strategies in the prediction of preference (Rachel Kaplan); Individual variations in landscape description (Kenneth H. Craik); Perception and prediction of scenic resource values of the Northeast (Ervin H. Zube, David G. Pitt, and Thomas W. Anderson); Application of a landscape-preference model to land management (Robert O. Brush and Elwood L. Shafer). **LANDSCAPE RESOURCES AND MODELS:** The regional landscape concept for the Basel Region (Rolf M. Plattner); Landscape assessment of the Upper Great Lakes Basin resources: A macro-geomorphic and micro-composition analysis

(Kenneth J. Polakowski); A landscape assessment-optimization procedure for electric-energy corridor selection (Bruce H. Murray and Bernard Niemann); Model for evaluation of the visual-cultural resources of the Southeastern New England Region (R. Jeffrey Riotte, Julius Gy. Fabos, and Ervin H. Zube); Assessing landscape resources: A proposed model (Wayne D. Iverson); Assessing visual-cultural values of inland wetlands in Massachusetts (Richard C. Smardon); Visual and cultural components of the landscape resource assessment model of the METLAND study (Julius Gy. Fabos, William G. Hendrix, and Christopher M. Greene).

Zuk, William.

1973. Methodology for evaluating the aesthetic appeal of bridge designs. *Highw. Res. Rec.* 248:1-4.

Abstract

Two groups—one professionally trained in areas related to esthetics (e.g., artists, architects, and landscape architects) and the other a random group of nonprofessionals made comparisons of paired line drawings of various bridge designs. The line drawings enabled predetermined factors to be systematically varied while holding other factors constant. "The majority opinion of each group was used to establish the preference position. The results show that aesthetic preference is generally given to such factors as simplicity, slimness, symmetry, conformity to the site, and expressions of out of the ordinary characteristics." The study found the two groups in general agreement on most points of form. 10 refs.

Critical Comments

The findings of this study illustrate the congruence of professional and public esthetic evaluations, frequently reported by other researchers, e.g., see Rabinowitz and Coughlin (1971, p. 21), Zube (1974, p. 26), Daniel and Boster (1976, p. 15).

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Arthur, Louise M., and Ron S. Boster.

1976. Measuring scenic beauty: A selected annotated bibliography. USDA For. Serv. Gen. Tech. Rep. RM-25, 34 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Of the 167 papers covered, 95 percent date from 1965. Citations are divided into four categories: literature reviews, inventory methods, public involvement, and miscellaneous. Many annotations also carry a "critical comment."

Keywords: Esthetics, land use planning, landscape management, inventory.

Arthur, Louise M., and Ron S. Boster.

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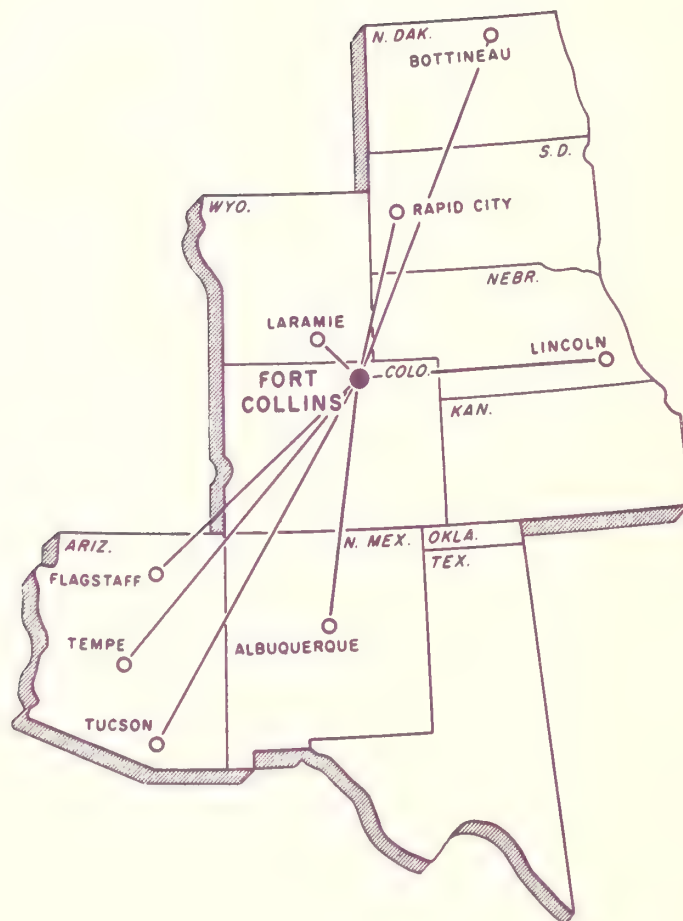
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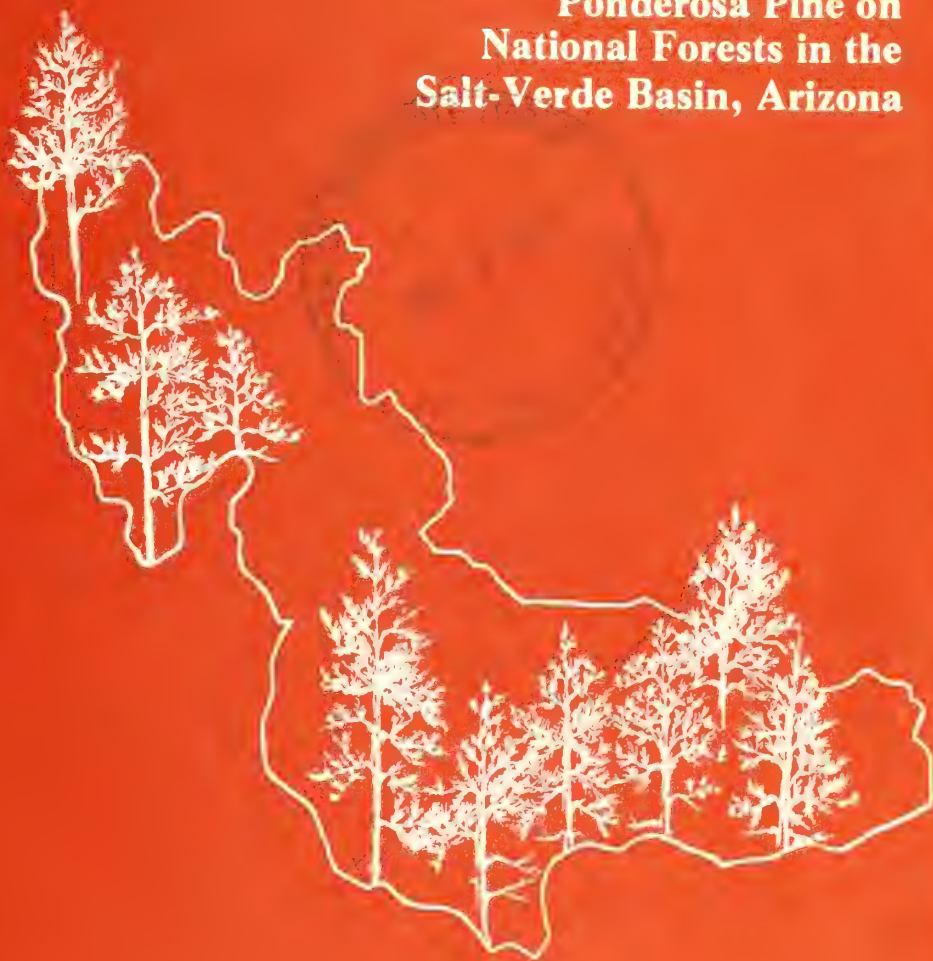
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June 1976

**A Descriptive Inventory of
Ponderosa Pine on
National Forests in the
Salt-Verde Basin, Arizona**



Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Senn, Ronald A., Jr.

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Keywords: *Pinus ponderosa*, Salt-Verde Basin.

A Descriptive Inventory of Ponderosa Pine on National Forests in the Salt-Verde Basin, Arizona

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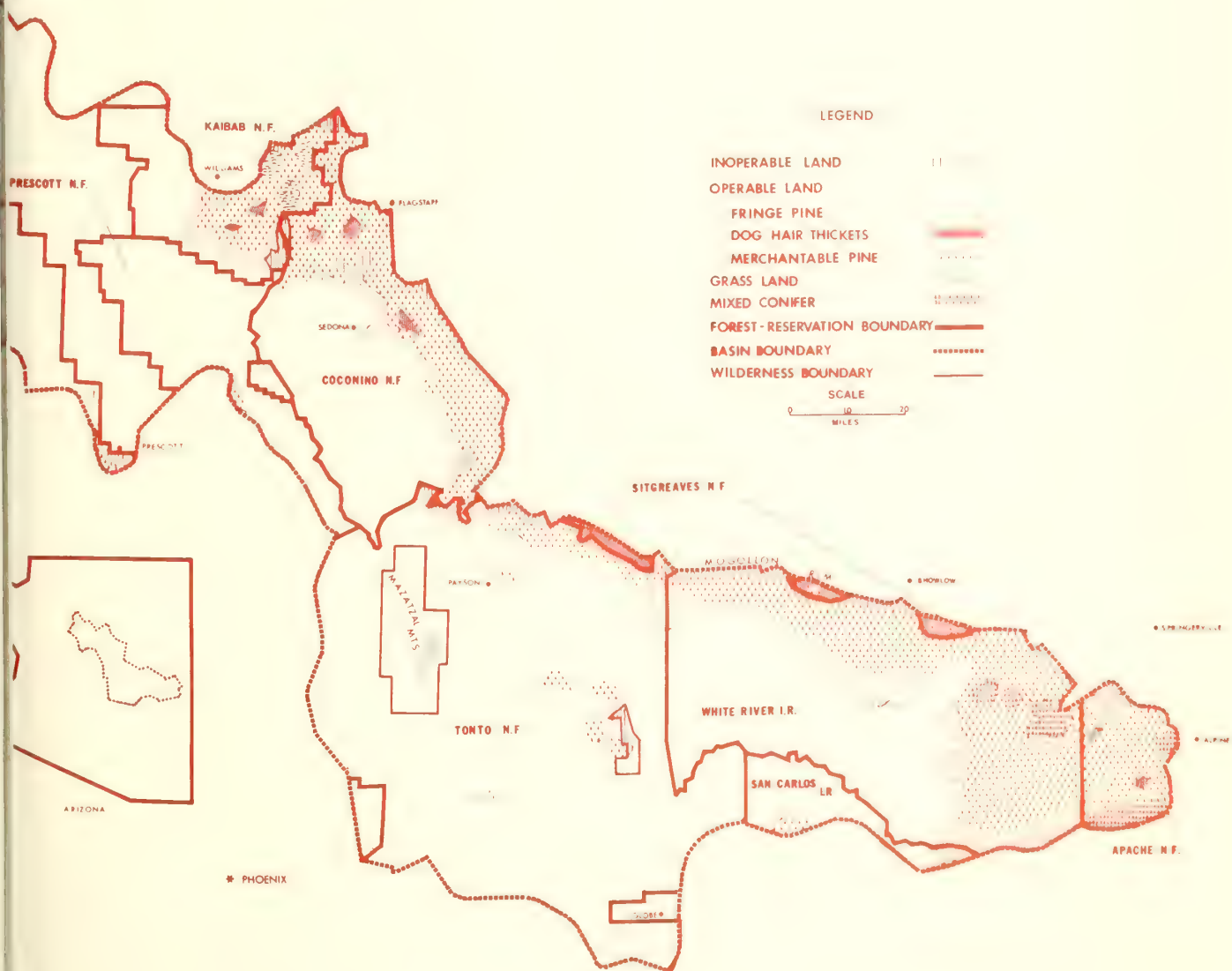
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A Descriptive Inventory of Ponderosa Pine on National Forests in the Salt-Verde Basin, Arizona

Objectives

More intensive land use planning will require better evaluation of resource management alternatives. A primary consideration in the evaluation process is knowledge of the current resource base.

The purpose of this survey was to describe the commercial ponderosa pine within the Salt-Verde Basin, Arizona (fig. 1). Continuous forest inventory (CFI) information provided the data base. Although CFI data exist for all major Basin ownerships, this inventory analysis was limited to ponderosa pine on National Forest lands.



This inventory will not replace pre-timber sale compartment examinations. Instead, it will be used as a base for evaluating broad management alternatives for the National Forest ponderosa pine area within the Basin.

Commercial Forest Land Components Defined

The specific components of the commercial forest land are based on the land's productivity and logging capability. Lands currently producing, or capable of producing, a minimum of 20 cubic feet of industrial wood fiber per acre per year (Green and Setzer 1974) are defined as commercial forest land (CFL).

Ponderosa pine covers over 90 percent of the National Forest CFL in the Basin (table 1). Ponderosa pine occurs either in pure stands or in mixed stands primarily associated with Douglas-fir, pinyon pine, alligator juniper, aspen, and Gambel oak. The delineated area is essentially a continuous forest extending for over 225 miles along the Mogollon Rim in central Arizona (fig. 1).

Table 1.--Total area of commercial forest land (CFL) in Arizona (Green and Setzer 1974)

Location	Ponderosa pine		Mixed conifer ¹		Total CFL
	<i>M acres</i>	%	<i>M acres</i>	%	<i>M acres</i>
Salt-Verde Basin	1,610	90.6	168	9.4	1,778
Other	1,628	87.6	231	12.4	1,859
Total	3,238	89.0	399	11.0	3,637

¹Includes aspen, Douglas-fir, white fir, corkbark fir, white pine, blue spruce, and Engelmann spruce.

Commercial forest lands are either inoperable or operable. Currently, the distinction between these two components is based on the presence or absence of constraints associated with sawtimber logging; however, future operability restrictions could be based on different land use and timber product constraints. Commercial forest land is classified as follows:

Inoperable

- Physical restrictions
- Land use constraints
- Administrative directives

Operable

- Nonstocked
- Fringe pine
- "Dog hair thickets"
- Merchantable production

Inoperable Land

Inoperable lands are defined by the existence of logging constraints, which are further classified into their specific operational restrictions: physical, land use, and administrative.

Physical restrictions are primarily those that limit the operation of logging equipment. Steep slopes (greater than 35 percent), excessive surface rocks, and the lack of road and skid trail systems reduce the operable area. Current stumpage prices prohibit the use of more expensive logging techniques; however, future timber prices may change this situation. "Inoperable lands" in forestry are analogous to "proved reserves in oil." As the price of oil goes up, so do the proved reserves. Likewise, higher prices for wood decrease the amount of inoperable and increase the amount of operable land.

Land use constraints result from selecting the best possible management alternative for a specific planning area within a multiple use framework. Alternative uses are dictated by soil characteristics, ecological impacts, and economic and sociological considerations. Land use areas defined as inoperable in this paper are those where alternative multiple uses prohibit or severely restrict timber harvesting.

Physical and productivity properties of soil may also restrict logging operations. Ecological impacts are equally important, and include considerations for fauna, flora, and water, travel, recreation, and amenity influence zones.

Economic and sociologic factors are interlaced with the other considerations. Alternative management decisions must consider the tradeoffs that result in various amenity-commodity combinations.

Administrative directives supersede land use restrictions, and often result from legislative mandates. Examples are wilderness areas (permanent or proposed) and research study areas.

Operable Land

Operable commercial forest land is defined as the residual land remaining after the inoperable lands are withdrawn from the total CFL. The physical character of the land permits use of current logging techniques. Environmental, economic, and sociological considerations do not prohibit logging, but provide the basis for alternative decisions among methods and intensities of logging.

Operable land is characterized by a spectrum of productive capabilities. This inventory divides the operable land into four production components: nonstocked, fringe pine, "dog-hair thickets," and merchantable.

Nonstocked land is defined as operable land area capable of but not currently producing wood fiber. This area needs reforestation by artificial or natural regeneration techniques.

Fringe pine areas are characterized by scattered, limby pines producing poor quality wood at a rate near the lower limits of the commercial forest land definition. This pine component is heavily mixed with understories of pinyon pine, juniper, and Gambel oak. Fringe pine occurs primarily as a transition zone between the merchantable pine and the chaparral and pinyon-juniper vegetation types (see fig. 1). Site Class III² lands predominate, and typify the poor site conditions found in this component.

"Dog-hair thickets" (dense stands with basal areas exceeding 150 ft² per acre) of precommercial size classes cover scattered areas within the Basin. Wood production per acre may be classified as adequate, but the production per tree often falls below the site capabilities. Many of these stands have maintained this stagnated condition for over 50 years and have yet to reach pulp and sawtimber size classes. These

²Site Class III, II and I include site index ranges 0-54, 55-74, and 75+, respectively.

thickets are evident on lands throughout all site class ranges.

The **merchantable production** component is defined as the area which contributes the major portion of the harvest volume. The lands are primarily Site I and Site II areas. Current harvesting includes primarily pulp and sawtimber wood products; future harvests are expected to include a larger product variety.

Data Sources and Collection Methods

Descriptions of ownership, composition, distribution, and production were developed from a wide range of sources in order to delineate distinct soil productivity groups and corresponding stand tables for each forest.

Vegetation and Ownership Stratification

The pine vegetation areas were delineated on maps (scale: 1/2 inch = 1 mile) (Brown 1973), and the commercial pine component verified with National Forest personnel. Ownership of the commercial pine component (fig. 2) was stratified using National Forest and U.S. Geological Survey topographic maps. Additional information was obtained from Forest personnel and from previous publications (Barr 1956, Ffolliott et al. 1972, Green and Setzer 1974).

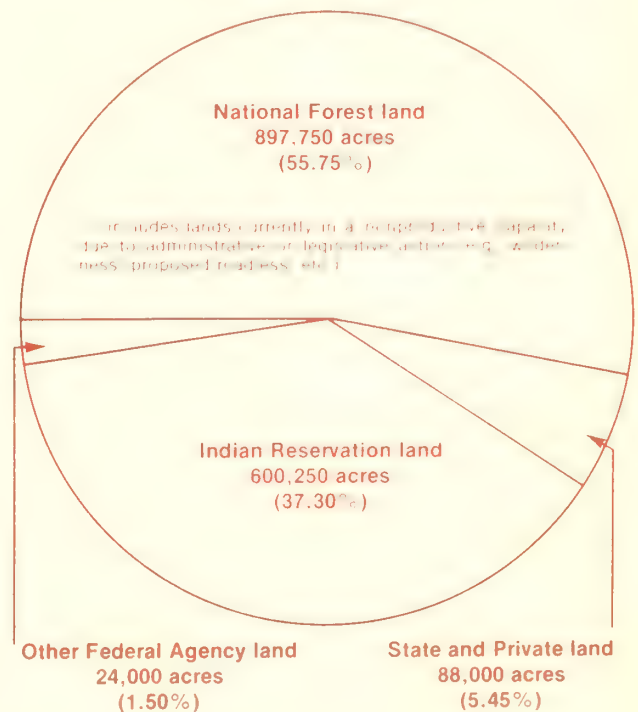


Figure 2.—Ownership patterns of the ponderosa pine commercial forest land in the Salt-Verde Basin, Arizona.

Soil Analysis

The objective of the soil analysis was to group soils with similar timber productivities. Frequency distribution curves of site index from continuous forest inventory data points were plotted for the soils within each National Forest. Figure 3 shows hypothetical examples of the frequency curves found to exist for igneous and sedimentary soils. Metamorphic formations constituted less than 1 percent of the Basin commercial forest area, and were eliminated from further consideration.

Igneous soil distributions formed distinct groups, which were related to specific soil types (for example,

Springerville, Broliar, and Sponseller). Site index variability was related to differences in soil properties such as soil depth, infiltration capacity, and rockiness. The distributions were not of equal size, but each represented only one soil type. Distributions overlapped at the lower frequency levels (fig. 3).

Sedimentary soil distributions did not exhibit distinct groups (for example, Cherry Creek, Dandrea, and Zane, fig. 3). Sedimentary site index variation was not evident *between* soil types but rather *within* soil types. The site index differences within soil types result from physiographic characteristics such as slope, aspect, and elevation.

The frequency distribution curves illustrated the range in site index for each soil type and facilitated

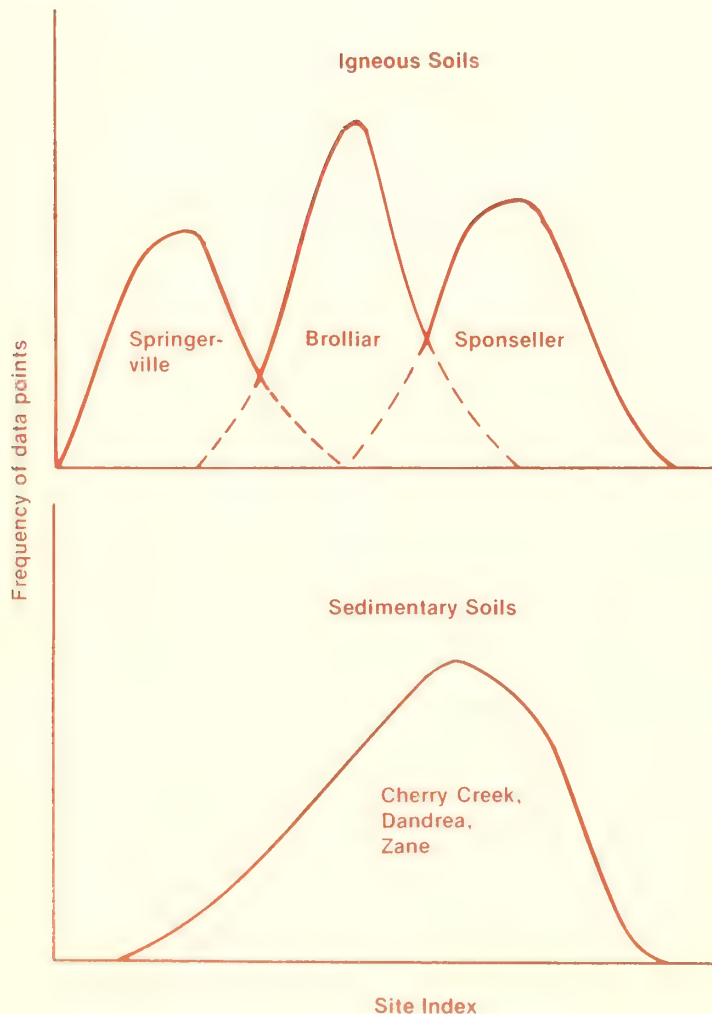


Figure 3.—Hypothetical site index frequency distribution curves.

determination of the average site index.³ Combining soils having similar average site indices resulted in 14 soil productivity groups.⁴ The areas represented by each group were delineated and overlaid on the commercial forest maps previously developed. Stand areas in acre units were determined using a planimeter.

Stand Table Analysis

Stand character descriptions were developed for each of the 14 soil groups.⁵ Maps showing the Continuous Forest Inventory (CFI) ground plot points were overlaid on the previously developed soil maps. All CFI points within each soil group were averaged together to develop stand tables showing trees per acre by 2-inch diameter classes (seedling to 40 inches). Average stand basal areas and board-foot volumes were computed from the CFI data. There was no significant difference in stand basal areas and board-foot volumes computed using a computer simulation model for ponderosa pine growth (Larson 1975). CFI inventory dates and number of data points within the Basin were:

National Forest	Inventory date	Number of data points
Apache	1965	81
Coconino	1969	97
Kaibab	1966	83
Prescott	1970	49
Sitgreaves	1971	16
Tonto	1968	98
Total		424

Commercial Forest Land Component Analysis

After the stand table descriptions were completed, estimates of the various productive components of the CFL were developed (fig. 4). The primary sources included communication with National Forest and forestry industry personnel. Every attempt was made to gather all known information on the inoperable, nonstocked, fringe pine, dog hair thicket, and merchantable production components. Personal field trips helped verify and describe the components.

³The weighted average site index for each soil type was computed from: $\frac{\sum f_i x_i}{\sum f_i}$

where x = site index, and f = frequency of data points.

⁴The old Apache and Sitgreaves National Forests were kept separate because of their distinct differences in soil and timber density characters.

⁵Stand character is also highly related to past management influences. These stand descriptions should be considered as a first approximation until logging history data are utilized to further describe their variation.

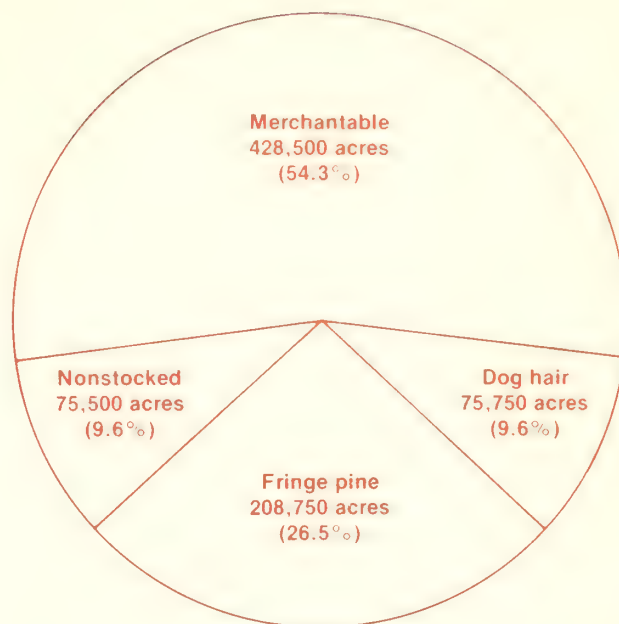


Figure 4.—Operable components of the National Forest ponderosa pine commercial forest land in the Salt-Verde Basin, Arizona.

Nonvegetative Information

Additional inventory information on nonvegetative characteristics was gathered to be used as input for forage and runoff estimates. U.S. Geological Survey topographic and precipitation (1931-60) maps and forest soil reports provided measures of slope, soil depth, annual precipitation, and winter precipitation.

Results

General Area.—The total commercial forest land (CFL) in Arizona is 3.64 million acres (Green and Setzer 1974). The Salt-Verde Basin contains 48.9 percent (1,778,000 acres) of the total, with ponderosa pine comprising 90.5 percent (1,610,000 acres) of the Basin CFL.

National Forests.—The total CFL under Forest Service jurisdiction is 897,500 acres, with 12.2 percent classed as inoperable at this time. The operable land (788,500 acres) is subdivided into nonstocked (75,500 acres), fringe pine (208,750 acres), dog hair thickets (75,750 acres), and merchantable (428,500 acres) (fig. 5). The Coconino National Forest has 44.3 percent (349,500 acres) of the Basin operable CFL, while the Sitgreaves National Forest has only 2.2 percent (17,500 acres) (fig. 5). The proportion of

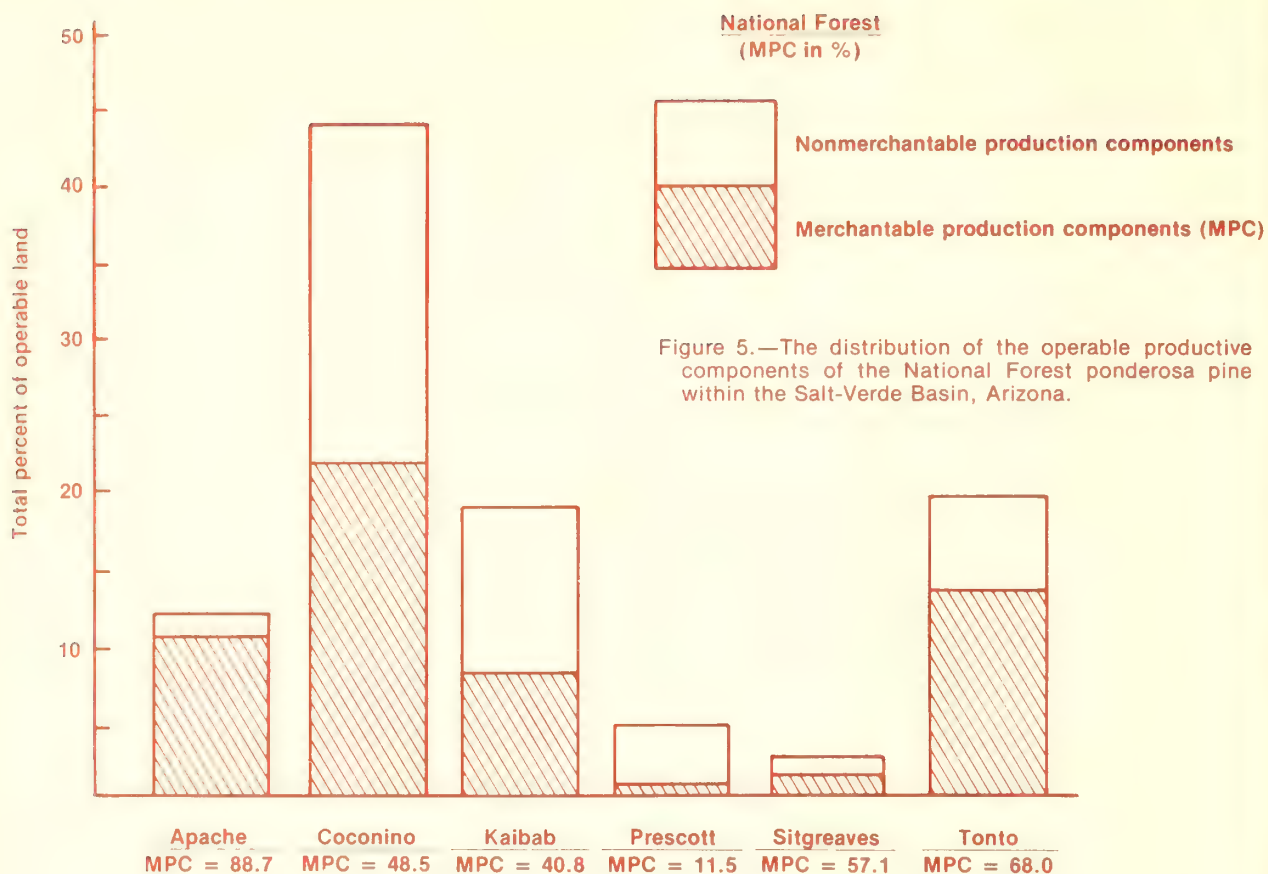


Figure 5.—The distribution of the operable productive components of the National Forest ponderosa pine within the Salt-Verde Basin, Arizona.

merchantable to nonmerchantable land varies among the Forests. For example, relative to the total operable land, the Apache National Forest has the highest percentage of merchantable production component, 88.7 percent (83,000 acres), while the Prescott National Forest has the lowest percentage, 11.5 percent (3,500 acres). The relationships of the other National Forests are shown in figure 5.

Soil Type Distribution.—The National Forest timber soils are derived from igneous (67.6 percent) and sedimentary (32.4 percent) geologic formations. Geological soil formation importance can be realized by comparing the total individual soil CFL area to its total merchantable production area. The Sponseller soil complex covers 12.8 percent of the total Basin operable CFL, but supports 20.4 percent of the merchantable component. Without exception, all of the sedimentary soils support a larger percentage of the merchantable component (39.4 percent) than the CFL lands (32.4 percent). The increases noted are related to the percentage of nonstocked, fringe pine, and dog hair acreages, which is smaller than on the poor soil types (Brolliar/Stoneman, Springerville/Thunderbird/Cabazon variants). Table 2 depicts this relationship for all of the major timber soil types found in the Basin.

Table 2.—Soil type distribution for the total operable commercial forest land (CFL) and the merchantable production component (MPC) ponderosa pine on the National Forests within the Salt-Verde Basin

Geological formation and soil type	Percent of total CFL	Percent of total MPC
Igneous	67.6	60.6
Sponseller	12.8	20.4
Brolliar/Stoneman	50.6	39.7
Springerville/Thunderbird		
Cabazon variants	4.2	0.5
Sedimentary	32.4	39.4
Soldier	3.7	5.5
McVickers	6.7	8.8
Amos, Bearhead, Mirbal		
Reynolds, Workman, and Zane	7.6	10.8
Cherry Creek, Colcord, Dandrea, Diamond Rim, and Verde	14.2	14.3

Table 3, 4, and 5 show acreage components, stand table descriptions, and stand compositions, respectively.

Table 3.--Ponderosa pine commercial forest land (CFL) acreages for the National Forests within the Salt-Verde Basin¹

National Forest and Group No.	CFL Totals	Inoperable lands ²	Operable lands			
			Nonstripped	Fringe pine	Open pine	Merchantable
Apache						
1	51,000	1,500	500	1,500	2,000	46,000
2	45,000	1,000	1,000	2,500	3,000	40,500
Coconino						
3	34,500	4,800	1,200	3,500	1,000	25,000
4	46,500	7,400	1,800	5,500	2,000	29,800
5	278,000	26,800	27,000	80,000	1,000	184,200
6	34,000	4,500	13,000	15,000	1,000	5,500
Kaibab						
7	13,500	1,400	500	2,000	1,500	8,100
8	112,000	1,300	10,000	1,000	12,500	88,200
9	25,000	1,800	1,500	9,000	500	2,200
Prescott						
10	39,000	8,500	4,000	22,500	250	2,500
Sitgreaves						
11	19,000	1,500	2,000	1,500	4,000	10,000
Tonto						
12	95,450	35,450	800	1,000	2,200	46,100
13	99,300	11,800	1,650	24,400	4,550	65,900
14	5,500	1,500	550	3,200	250	100
Total	897,750	109,250	75,500	208,750	75,750	428,500

¹Enclosed private and State lands deducted.

²Wilderness and research study areas are included.

Table 4.--Average productivity group descriptions

National Forest and Group No.	Soil type and formative factors	Soil productivity (with major variants)	A horizon depth	Stem density	Stem diameter	Stem volume	Stem weight	Stem length	Stem diameter	Stem length	Stem diameter	Stem length	Stem diameter
Apache													
1	Ig.	Sponseller	8	26	14	0.73	80	844	102	4.7	3.76	10,266	
2	Ig.	Brolliar (10%)	6	24	13	.71	70	408	58	5.1	3.57	3,779	
Coconino													
3	Sd.	Soldier	9	26	17	.73	85	589	127	6.3	10.12	10,338	
4	Sd.	McVickers (80%)	8	24	14	.71	70	408	58	5.1	3.57	3,779	
5	Sd.	Colcord (20%)	6	24	13	.71	70	408	58	5.1	3.57	3,779	
6	Ig.	Thunderbird/Cabezon var.	3	24	12	.71	70	408	58	5.1	3.57	3,779	
Kaibab													
7	Ig.	Sponseller	8	26	17	.74	80	844	102	4.7	3.76	10,266	
8	Ig.	Brolliar	6	24	14	.72	70	408	58	5.1	3.57	3,779	
9	Ig.	Stobbs	7	24	13	.71	70	408	58	5.1	3.57	3,779	
Prescott													
10	Sd.	Mirabal/Dandrea (70%)	5	24	13	.71	70	408	58	5.1	3.57	3,779	
Sitgreaves													
11	Sd.	McVickers (80%)	8	24	14	.71	70	408	58	5.1	3.57	3,779	
Tonto													
12	Sd.	Amos, Bearhead, Reynolds, Workman, and Zane	5	28	18	.72	75	800	59	4.6	3.66	2,665	
13	Sd.	Cherry Creek, Colcord, Diamond Ranch, Little Ranch, and Verde	4	26	17	.71	70	480	58	4.6	4.76	2,665	
14	Ig.	Thunderbird/Cabezon var.	2	24	12	.71	70	408	48	4.6	4.06	1,372	

¹Ig. = Igneous, Sd. = Sedimentary.

²Scribner.

Table 5.--Ponderosa pine stand tables, by 2-inch diameter size classes, for 14 soil groups on the National Forests within the Salt-Verde Basin

Diameter size classes (Inches)	Apache		Coconino				Kaibab			Pres- cott	Sit- greaves	Tonto		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
----- trees per acre -----														
seedling	403.5	177.5	170.0	206.3	277.3	192.5	125.9	100.9	103.5	82.4	675.0	229.5	209.0	187.5
2	243.2	84.4	109.3	148.9	95.3	104.4	85.4	63.3	35.4	39.2	140.0	127.5	120.0	84.9
4	110.3	71.3	120.0	133.1	40.8	48.9	58.4	53.2	32.1	33.0	50.1	53.9	58.7	47.3
6	18.9	27.6	69.7	60.9	26.6	40.5	40.6	37.0	21.8	32.9	25.9	40.7	36.9	38.4
8	17.5	18.3	52.1	48.9	22.9	31.8	26.5	23.8	14.7	21.2	18.9	24.2	22.2	27.9
10	11.5	8.4	24.3	28.1	9.0	8.5	15.7	16.2	12.2	13.3	11.9	15.8	13.7	8.3
12	8.7	5.3	18.2	11.6	8.7	5.6	13.9	12.6	4.9	9.9	9.3	9.5	9.0	5.3
14	7.5	4.5	8.8	4.7	4.8	3.7	6.2	5.2	3.1	7.0	4.5	5.2	4.9	3.5
16	5.1	2.8	3.7	4.1	3.9	1.8	4.2	3.1	1.5	3.4	3.9	2.4	2.3	1.7
18	4.5	2.2	2.6	3.0	3.3	1.3	3.1	1.4	.9	2.2	2.0	1.7	1.6	1.3
20	3.7	1.8	2.3	2.5	2.6	.7	2.8	1.6	.8	1.0	1.7	.8	.8	.6
22	3.8	1.6	1.9	2.3	2.7	.9	1.7	1.0	.4	.6	2.2	.6	.5	.6
24	3.2	.6	1.8	1.8	1.2	.6	1.2	.6	.2	.3	.6	.3	.3	.6
26	1.2	.5	1.2	1.0	.9	.3	.7	.5	.1	.3	.6	.3	.3	.4
28	.8	.3	1.3	.5	.5	.2	.6	.2	0.0	.2	.4	.1	.1	.2
30	.7	.4	.8	.4	.1	.2	.1	0.0	0.0	0.0	.1	.1	.1	.1
32	.1	0.0	.3	.3	.1	.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	.1	0.0	.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
36+	0.0	0.0	.1	0.0	0.0	0.0	0.0	0.0	0.0					

¹A "0" indicates between zero and .1 tree per acre.

Literature Cited

Barr, George W.

1956. Recovering rainfall, Part I. Arizona Watershed Program. Cooperating: Ariz. State Land Dep., Water Div., Salt River Valley Water User's Assoc., Univ. Ariz., 33 p.

Brown, David E.

1973. The natural vegetative communities of Arizona. Ariz. Game and Fish Dep., Phoenix (map).

Ffolliott, Peter F., David L. Fisher, and David B. Thorud.

1972. A physiographic survey of the ponderosa pine type on the Salt-Verde River Basin. Ariz. Agric. Exp. Stn., Tech. Bull. 200, 60 p.

Green, Alan W., and Theodore S. Setzer.

1974. The Rocky Mountain timber situation, 1970. USDA For. Serv. Resour. Bull. INT-10, 78 p.

Larson, Frederic R.

1975. Simulating growth and management of ponderosa pine stands. Ph.D. Diss. Colo. State Univ., Fort Collins, 118 p.

Senn, Ronald A., Jr.

1976. A descriptive inventory of ponderosa pine on National Forests in the Salt-Verde Basin, Arizona. USDA For. Serv. Gen. Tech. Rep. RM-26, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

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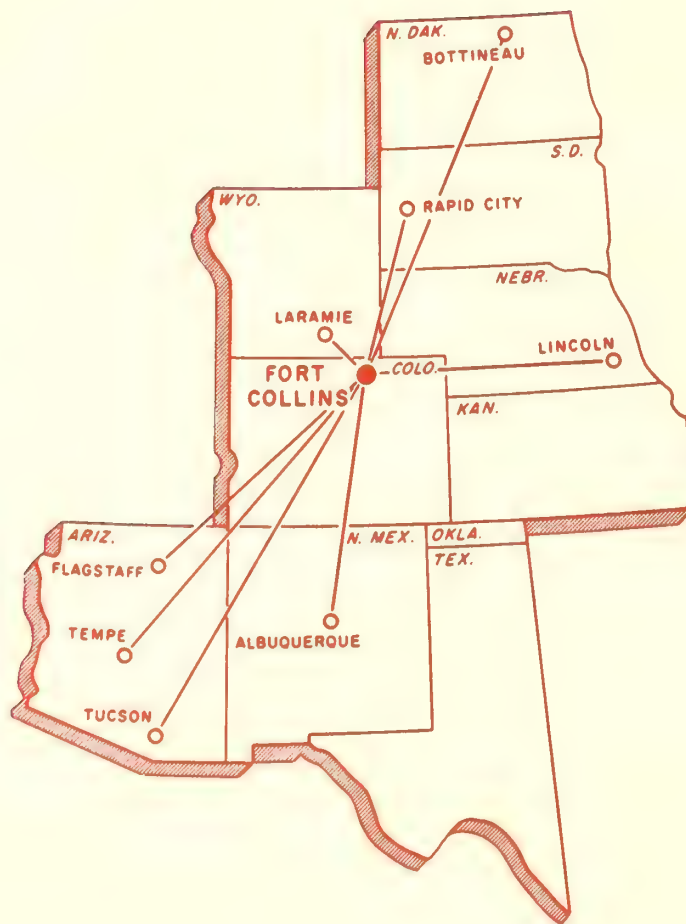
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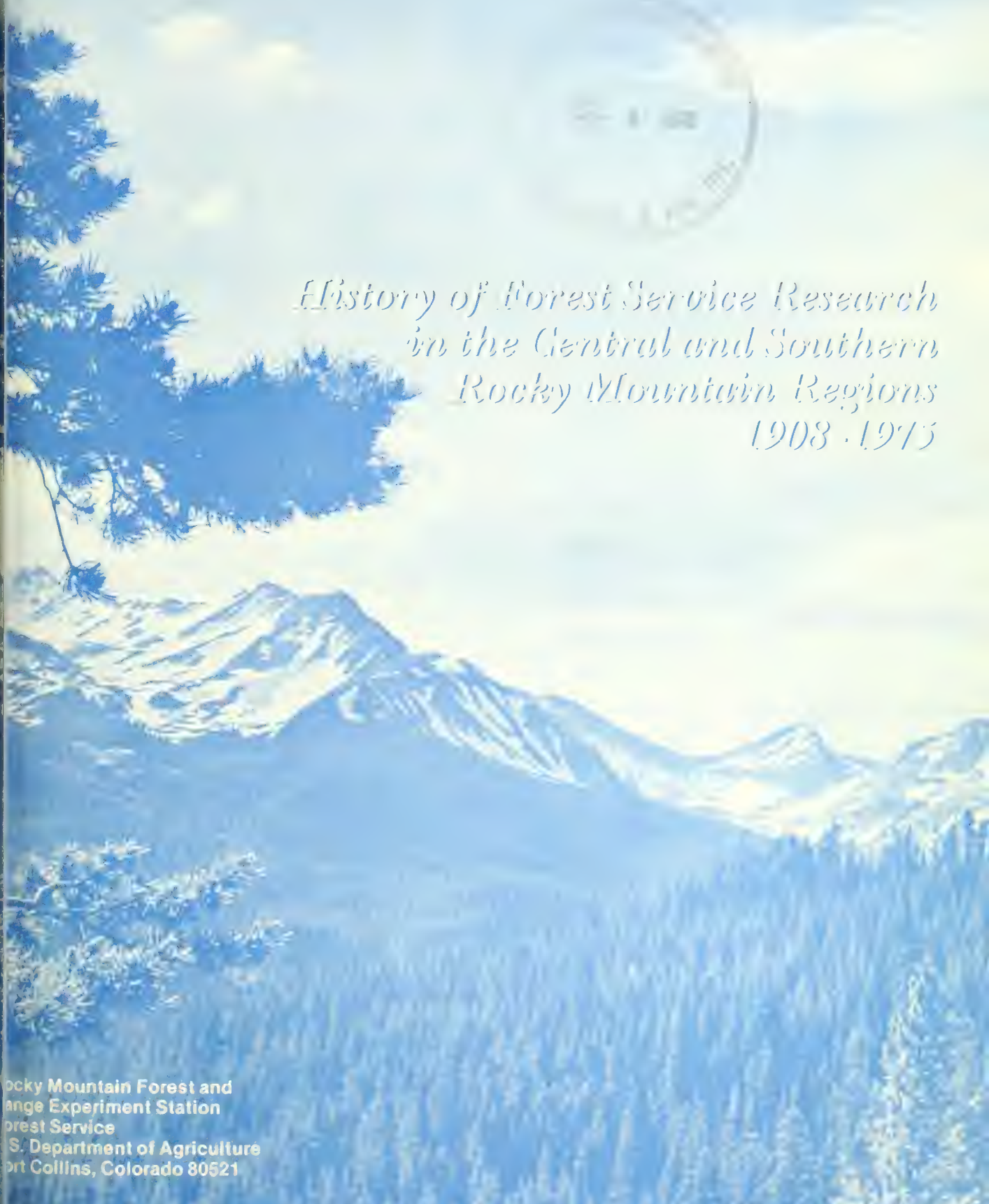
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Forest Service Research Report 8887

Forest Service



*History of Forest Service Research
in the Central and Southern
Rocky Mountain Regions
1908-1975*

Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Price, Raymond.

1976. History of Forest Service Research in the Central and Southern Rocky Mountain Regions, 1908-1975. USDA For. Serv. Gen. Tech. Rep. RM-27, 100 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

The first forest research area established by the Forest Service was in 1908—the Fort Valley Experimental Forest near Flagstaff, Arizona. In 1909, the Fremont Experiment Station near Colorado Springs was begun, as well as the Wagon Wheel Gap watershed experiment in the central Rockies. The Santa Rita Range Reserve, begun in 1903, was transferred to the Forest Service in 1915. Two forest and range experiment stations were officially designated—Southwestern Station, in 1930, at Tucson, Arizona, and Rocky Mountain Station, in 1935, at Fort Collins, Colorado. The two Stations were combined in 1953, with central headquarters at Fort Collins, to serve a 10-State territory.

Keywords: USDA Forest Service, forestry research, history.

**History of Forest Service Research
in the
Central and Southern Rocky Mountain Regions
1908-1975**

Raymond Price¹

¹Raymond Price, retired, was Director of the Southwestern Forest and Range Experiment Station with headquarters at Tucson, Arizona, from 1942 to 1953. In 1953, the Southwestern and Rocky Mountain Stations were consolidated, with headquarters at Fort Collins, Colorado, where Price served as Director from 1953 to 1971. The Rocky Mountain Forest and Range Experiment Station maintains central headquarters at Fort Collins, in cooperation with Colorado State University.

Foreword

The Nation's Bicentennial — 1976 — also marks the Centennial for federal forestry in the United States. Forestry research became an integral part of the Nation's earliest efforts to base forestry and other land management practices on sound scientific footing.

Forests and their related resources provided our forebears with much of the raw material they needed to build our country. These resources are even more important to our national welfare now than they were in 1876 or 1776.

Today, resource managers possess tools for doing their jobs that were only dreamed of by Gifford Pinchot and other forestry pioneers at the beginning of the 20th Century. The modern manager knows how to plan forestry practices that will get much more from timber, range, wildlife, water, and recreation resources than was possible in earlier years — and he can do it while retaining, or even improving, scenic beauty and other environmental values.

Research made these resource management advances possible. We believe this history lends a perspective to the role of the Rocky Mountain Forest and Range Experiment Station, and its predecessors, in the efforts of the Forest Service in the West. Some of the earliest organized research in the Forest Service began here: timber management research at Fort Valley in Arizona, watershed management research at Wagon Wheel Gap in Colorado, and range management research at Santa Rita and Jornada in Arizona and New Mexico.

In the field of timber management research, scientists have sought answers to long-term challenges associated with forest regeneration, improving growth and yield, and protecting forests from insects, diseases, and fires. Means of handling several problems in these areas have been worked out, and foresters have applied the results.

Guidelines for managing rangelands in the central Rockies and Southwest were nonexistent at the turn of the century. Our researchers have cooperated with managers to devise grazing systems that prevent range abuse, methods for controlling poisonous plants, and techniques for restoring depleted ranges to productivity.

Watershed management research has been one of our significant pioneering efforts. We have developed information on erosion potential for forest and rangelands, and have devised ways to control soil loss and avoid decline in water quality. We have also developed techniques for managing vegetation, and snow accumulation, as means for altering the volume and timing of streamflows from mountain watersheds.

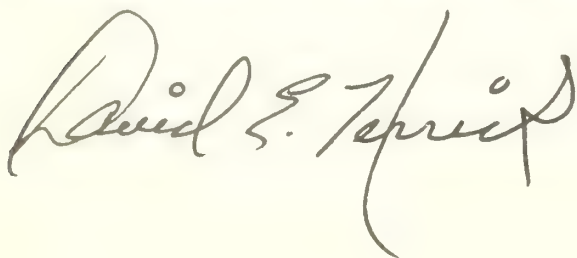
In recent years rapid population growth in many areas of the West, including expanding recreation and community developments in the mountains, has boosted demands for all resources. Our research is responding to these shifts by developing practical tools to help land managers devise better ways to meet diverse public needs while preserving environmental beauty and productivity.

We're proud of our forestry research history. But even more, we're proud of the people who made that history. This document records the efforts of a number of those people, although time and space would not permit everyone to be mentioned, or the detail given to their work that we might like. Men and women together have shared in our mistakes and our accomplishments. Their efforts have built the foundation for future research — research that we hope will be increasingly effective in helping to solve major forest and range resource challenges in the Great Plains, the Central and Southern Rockies, and the Southwest.

As we considered assembling the Station's history, we asked ourselves who could best organize and describe nearly 7 decades of research spread over a 10-State territory. Ray Price was our immediate choice. No other individual has personally known and dealt with so many facets of the Station's work over so many years.

Ray accepted the challenge and tackled the task with the same vigor he exhibited during his years as Station Director. He dug into old reports and contacted retirees and others to ferret out significant events — and some stories on the lighter side — that would illustrate why various research programs were organized and the significance of their results. We are indebted to Ray for completing this difficult job.

For the constructive criticisms made of this history, we gratefully acknowledge the help of former Station Directors R. E. McArdle, C. A. Connaughton, W. G. McGinnies, and K. E. Wenger; former Chief of Range Research W. R. Chapline; former Assistant Directors and Branch Chiefs S. R. Andrews, G. L. Hayes, M. D. Hoover, B. R. Lexen, E. H. Reid, and N. D. Wygant; and various members of the current Station staff.



DAVID E. HERRICK

Director

Rocky Mountain Forest and Range Experiment Station

August 1976

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

U.S. DEPARTMENT OF AGRICULTURE

6-76

FOREST SERVICE

Directors

Rocky Mountain Station
1935-53

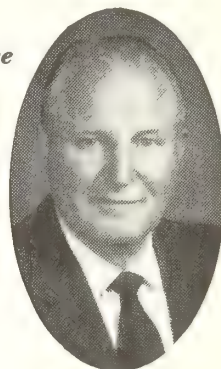
R. E. McArdle

C. A. Connaughton

Directors

Combined Rocky Mountain Station
1953-75

R. Price



G. McGinnies



K. F. Wenger



D. E. Herrick

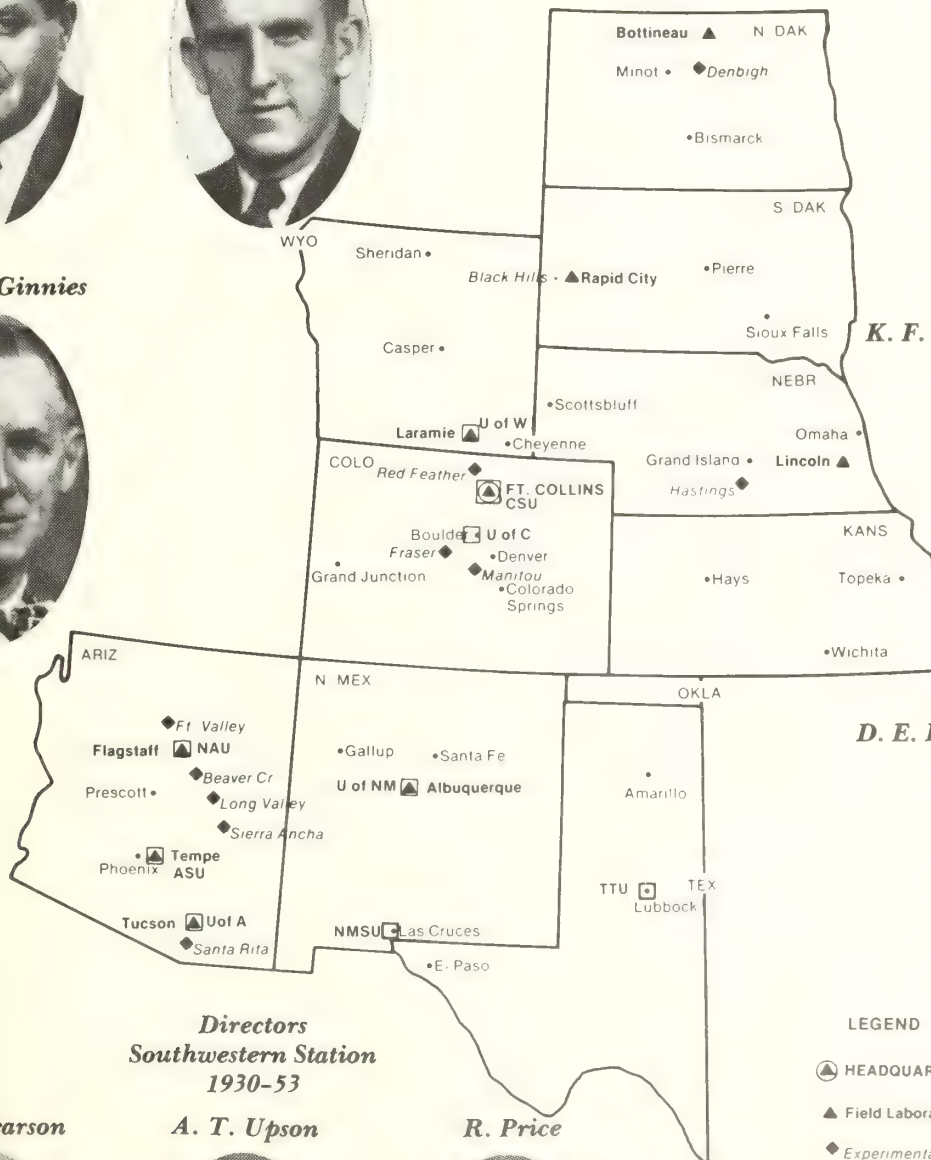


Directors
Southwestern Station
1930-53

G. A. Pearson

A. T. Upson

R. Price



LEGEND

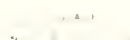
▲ HEADQUARTERS

▲ Field Laboratories

◆ Experimental Areas

□ Eisenhower Consortium Universities

• Major communities in addition to laboratory locations



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"Here We Shall Plant the Tree of Research"

In August 1908, the U.S. Forest Service began its formal timber management research with the establishment of the Fort Valley Forest Experiment Station near Flagstaff, Arizona. This was the first scientific venture of its kind in America—now the oldest.

Following is a reflection about the establishment of the Fort Valley Forest Experiment Station by G. A. Pearson, pioneer Forest Service Silviculturist, the first director of the Station:



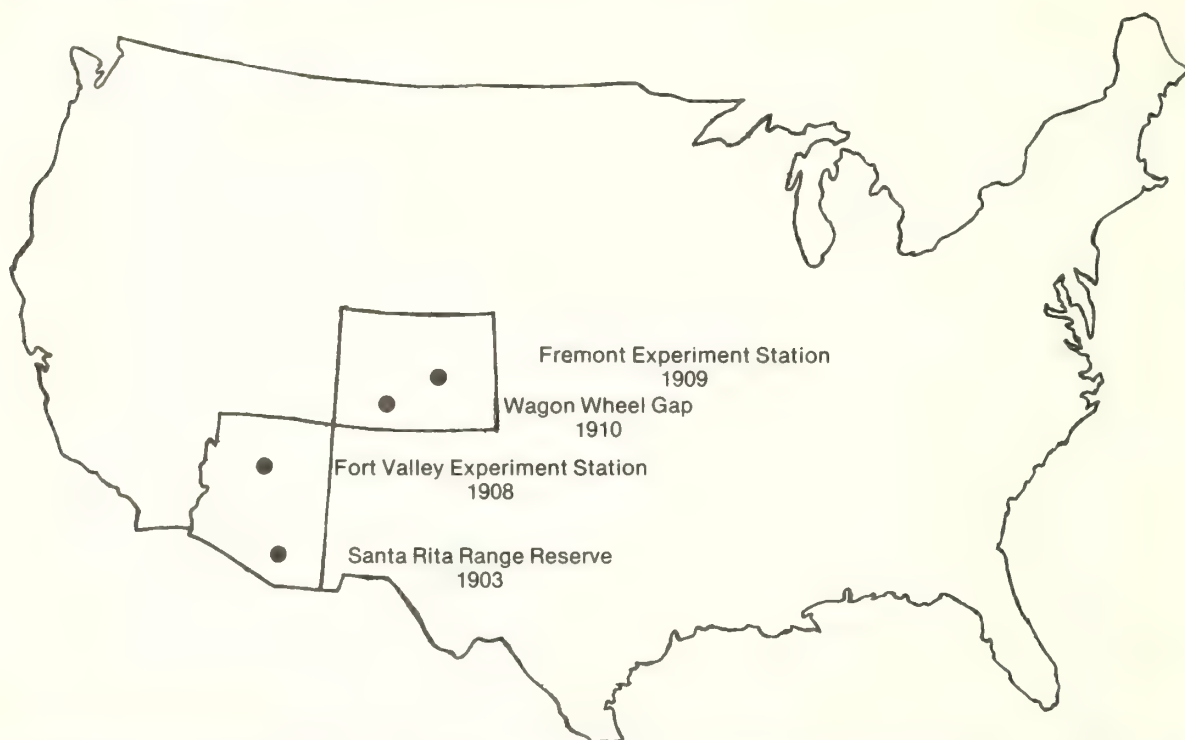
1

It was a sultry afternoon in August 1908. Raphael Zon, then chief of Silvics in the Forest Service, had come to Flagstaff to select a location for what was to be the first forest experiment station in the United States. Zon, Willard Drake, and I were urging our phlegmatic livery stable cayuses over the road to Fort Valley to examine a site that had been recommended by Frank Pooler, Supervisor of the Coconino National Forest. Two miles short of our destination a thunderstorm crashed down upon us in true Arizona style. The downpour was more violent than usual, so we took shelter in a large barn of the old A-1 Cattle Company. When we emerged an hour later, the normally dry Rio de Flag was running a hundred yards wide with a fluid whose color and consistency told plainly that the country was going to the dogs even in that early day. After crossing the 'river,' it was only half a mile to the area we had come to see—a beautiful stand of ponderosa pine. "Here," said Zon, "we shall plant the tree of research!"

The forest area selected was first called the "Coconino Experiment Station." In 1911 it was renamed the "Fort Valley Experiment Station." In the years following, a distinction developed between the "Experiment Station"—a group of scientists conducting research—and the "Experimental Forest"—the area on which the research was conducted. Later, the Fort Valley Experiment Station became one of several field laboratories of the Southwestern Forest and Range Experiment Station, now the Rocky Mountain Forest and Range Experiment Station.

The central and southern Rocky Mountain regions not only have the first experimental forest (Fort Valley) but also the first experimental range (the former Santa Rita Range Reserve near Tucson, Arizona, established in 1903), and the first experimental watersheds (the Wagon Wheel Gap watersheds on the Rio Grande National Forest in Colorado established in 1910). The experimental forest and experimental range are still in use, but the Wagon Wheel Gap watersheds have lain dormant since 1926.

2



Western yellow pine seedlings at Fort Valley were over 10 years old and taller than 6 inches when selected for a growth study. (Left to right) tree 44, in 1914, was 1.0 foot tall; in 1920, 2.7 feet; and in 1928, 5.2 feet tall.



The Central and Southern Rocky Mountain Regions

A Vast, Variable, and Valuable Empire

The central and southern Rocky Mountain regions—a 10-State area stretching from the Canadian border of North Dakota to Mexico—make a vast, variable, and valuable empire that comprises one-fourth of the land area of the conterminous 48 States.

Physiographically, the area is characterized by high mountains and true desert at the extremes, with high plateaus, rich mountain valleys, and high and low plains between. The natural vegetation reflects the accompanying climate.

Within this vast and variable empire are bounteous natural resources of water, timber, forage, wildlife, and recreational and scenic values that contribute much to the Nation's economy.

Unquestionably, water is the most important resource the area contributes to the western two-thirds of the Nation. Several major rivers of the West, including the Missouri, Platte, Arkansas, Canadian, Pecos, Rio Grande, Gila, and Colorado, have their origins in the Rockies. From these waters, irrigation and light and power are furnished for much of the West and Midwest. Cities and towns rely on mountain watersheds as their major source of water. And, mountain waters, held in multitudes of manmade lakes and reservoirs, provide prime outdoor recreation of a type that otherwise would not be available.

Some 80 percent of the lands is suitable, to some degree, for grazing of domestic livestock. Ranchers in the Rocky Mountain region derive over \$1 billion annually from livestock, many of which are grazed under permit on Federal lands, chiefly National Forests. Some 11 million cattle and 9 million sheep graze a third of their forage from these ranges, which vary from semidesert grass-shrub ranges to alpine grasslands.

Wood products have always been a continuing segment of the economy of the central and southern Rockies.

Commercial forests cover roughly 30 million acres; another 50 million acres are covered with noncommercial forest, primarily pinyon-juniper woodlands. The commercial forests support more than 108 billion board feet of sawtimber—32 billion cubic feet of net growing stock. The wood products industry is now in a transition stage, switching toward more specific product orientation—emphasis on remanufactured products rather than plain boards.

Over 1.5 million big-game animals are the primary drawing card for hunters. Mule deer head the list in terms of numbers, while elk are the prized trophies. There is no sure way to put a dollar value on the wildlife resource itself, but as an example of the values at stake, Colorado alone estimated the value added to the State's economy by sportsmen expenditures (hunting and fishing) at nearly \$329.4 million in 1973.²

The esthetics of a diverse wildlife population broadly overlap into the field of recreation. The food value of the game the hunter brings home is but a small part of the total value he derives from being in the forest or field. The scenic grandeur of its mountains and deserts, however, gives

²Nobe, K. C., D. M. Blood, and Lee Ann Ross. *Survey of sportsmen expenditures for hunting and fishing in Colorado, 1973.* (A contract report for the Div. Wildl., State of Colo., prepared by Dep. Econ., Colo. State Univ., Fort Collins.)








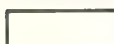



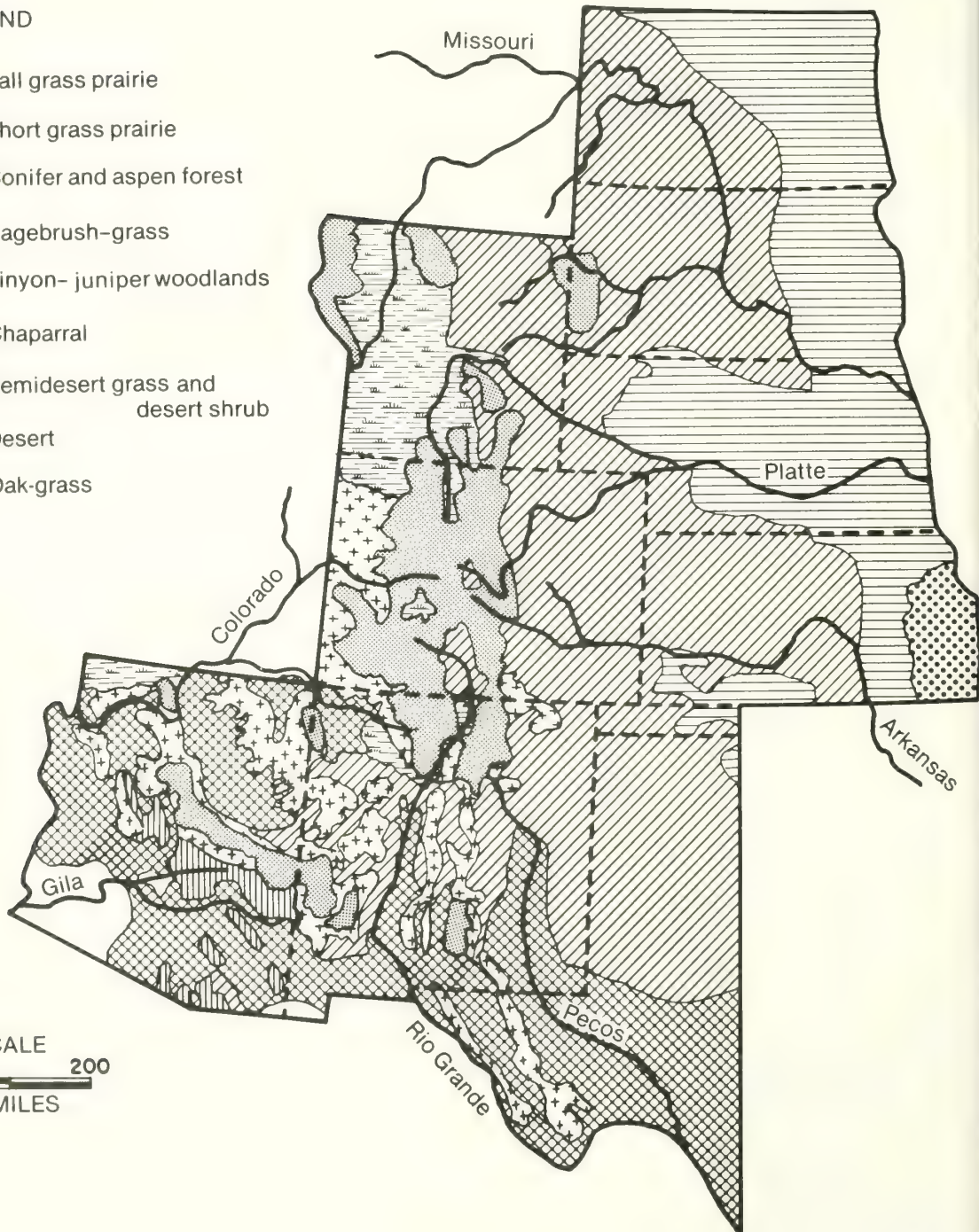
MAJOR RIVER DRAINAGES AND GENERAL VEGETATION TYPES

Rocky Mountain Forest and Range Experiment Station

March 1976

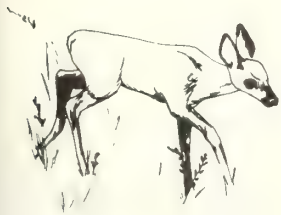
LEGEND

-  Tall grass prairie
-  Short grass prairie
-  Conifer and aspen forest
-  Sagebrush-grass
-  Pinyon-juniper woodlands
-  Chaparral
-  Semidesert grass and desert shrub
-  Desert
-  Oak-grass



SCALE
0 200
IN MILES

*A growing youngster in a
developing country.*



the area great interest to recreationists. National Forests within the area accounted for 18 percent of the visits or days' use for all the National Forests across the country in 1974, yet the area supports only 7 percent of the country's population. Winter sports, especially, are gaining rapidly in popularity. Recreation takes many forms in the central and southern Rocky Mountains, and encompasses all seasons.

Regions Used Early

Although the 10 States that make up the central and southern Rocky Mountain regions are officially young—7 are among the last 14 admitted to the Union—their history of use by the white man is old. Spanish explorers and settlers spread northwestward from Mexico over much of the region before the Pilgrims landed in New England. Early records show that a Jesuit missionary promoted livestock raising in southern Arizona in 1540. The Spanish settlers spread mostly over the lowlands, following the river courses back into the interior.

Settlement of the rugged, mountainous areas, and the prairies to the east, progressed slowly

until the late 1880's. Then several factors combined to cause boom growth: the construction of railroads to link East and West, the discovery of rich ores of gold and silver, and trail herds of cattle moving east from the Oregon Territory to Nebraska and Kansas railheads were a few.

Significantly, the lack of water—or perhaps more accurately, the erratic distribution of water—was a challenge even then to the development of communities and agriculture. Extensive irrigation systems were functioning as early as 1880.

Forests, especially those around developing communities, were logged off to provide necessary fuel, building lumber, fence and corral posts, mine timbers, and railroad ties. The tie hacks, especially, high-graded the forests in the railroaders' rush to connect the Coasts. Railroad construction also adversely affected the wildlife. Market hunters slaughtered great herds of game to provide meat for construction crews.

The range resource, too, was hit hard before the human population increased significantly. Livestock numbers soared to an early peak in 1885—over 5 million head of cattle, and nearly 10 million head of sheep. Overgrazing soon took its toll, and the herds suffered heavy losses during droughts and blizzards.

A Great Public Resource

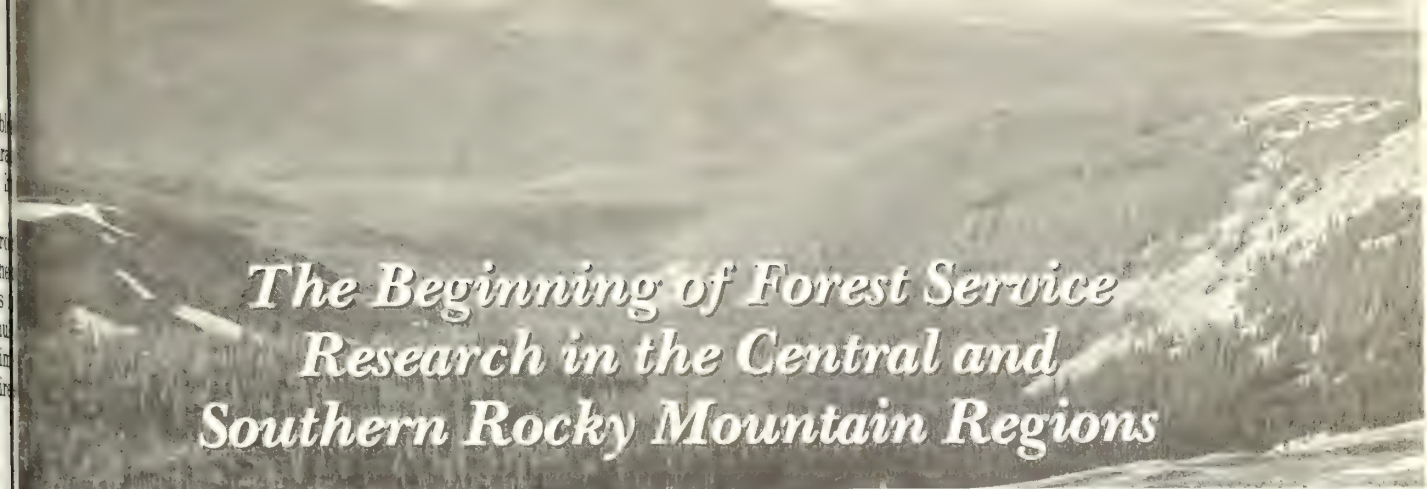
Large segments of the forest and rangelands in the central and southern Rocky Mountain regions are in public ownership and—significantly—a public responsibility. Moreover, a close mountain-valley relationship exists. What happens on or to the mountains directly affects the values and activities in the adjacent valleys and cities.

Here lies an immense piece of highly valuable real estate, its potential yields of renewable natural resources not yet fully known or appraised in terms of management guides.

The dominant value of the water resource requires that management and use of the other resources must often consider water yield as a limiting parameter. Thus, the economics of multiple-use relationships play an increasingly important role in the great Rocky Mountain empire.



A close mountain-valley relationship exists in the central and southern Rocky Mountain regions.



The Beginning of Forest Service Research in the Central and Southern Rocky Mountain Regions

Establishment of National Forests Made Forest Investigations Necessary

In 1891, when the Forest Reserves were created, little information or knowledge existed about the lands or the nature, value, and use of the resources. The boundaries had not even been defined on the ground, let alone any detailed information gained as to what was on them or how to properly use them.

The immediate task was to organize the Forest Reserves, later termed National Forests (1907), into some system for administration and inspection. A District plan, devised in 1907,³ formed six Districts for the then existing National Forests, with headquarters at Missoula, Montana (District 1); Denver, Colorado (District 2); Albuquerque, New Mexico (District 3); Ogden, Utah (District 4); San Francisco, California (District 5); and Portland, Oregon (District 6). Later, four more Districts were added, one in the West (Juneau, Alaska), two in the East (now combined into one at Milwaukee, Wisconsin), and one in the South (Atlanta, Georgia). Also, the term District was changed to Region. This history concerns primarily Regions 2 and 3. Region 2 geographic area now includes Colorado, Kansas, Nebraska, South Dakota, and eastern Wyoming; Region 3 includes Arizona and New Mexico.

Soon after the organization of the National Forests was completed, an important and vital

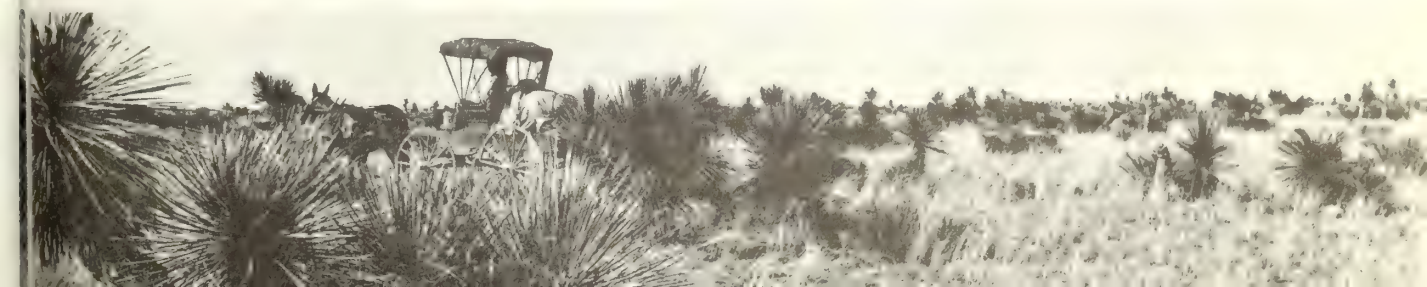
need was to learn about the several resources—their requirements and proper management and use. Management decisions had to be made without the benefit of assembled facts concerning the specific nature and capabilities of the resources. The challenge was how to go about getting the information and “know-how” as soon as possible.

Two closely related measures were adopted. The first was to encourage, assign, and approve Forest Officers in the field to observe, make notations, and conduct local administrative tests and studies. These were handled by heads of the Offices (later Divisions) of each Region handling each major resource, that is, Silvics (Timber Management), Grazing Management, and so forth. The other measure was to appoint and assign trained Forest Examiners (Silviculturists) and trained Grazing Examiners to each Region. These Forest and Range Examiners assigned by the Central Office of the Forest Service in Washington, D. C., were to give impetus to the local administrative studies made by Forest Officers, and to conduct more fundamental studies regarding the nature, requirements, and possible use of the resource.

An Office of Grazing Studies in the Washington Office was established in 1910 with James T. Jardine in charge. In 1911, Regional Offices of Grazing Studies were established in Districts 2 and 3. The offices had three main assignments, namely, range reconnaissance and management plan development for areas covered, technical range administration, and grazing studies.

³U.S. Department of Agriculture. 1908. *Report of the Forester for 1907*.

Jornada Range Reserve, New Mexico, 1913.



Chief Forester Henry S. Grave's Service Order 41, of January 2, 1912, set up a plan for Organization of Investigative Work. This Service Order created a Central Investigative Committee, and District Investigative Committees.⁴ The original Central Investigative Committee consisted of Raphael Zon, Chairman, representing the Branch of Silviculture; James T. Jardine, representing the Branch of Grazing; and Howard Weiss, representing the Branch of Products. This Central Committee reviewed, approved, and correlated the investigations in the several Regions nationwide. This matter of forest investigations was not taken lightly, because information was so vital to the proper use and management of the National Forest resources.

The District (now Region) Committees consisted of the District (Regional) Forester as chairman; members were the Forest and Range Examiners, Heads or Chiefs of the several Resources Offices or Divisions, and selected Forest Supervisors. From time to time other Forest Officers and representatives of other Federal and State agencies were invited to sit in on Committee deliberations. The Committee met annually to hear the results of the studies and investigations conducted during the year, discuss their application and use, and consider and approve the proposed program and studies for the coming year. The report of the Committee, which consisted of the reports of the several studies and investigations, together with the Committee action, was sent to the Central Investigative Committee in Washington, D. C.

Region 2 Investigations

Region 2 personnel got deeply involved in forest investigations, including range studies.⁵ They not only recognized the urgency to obtain resource information in guiding the use and management of the National Forests, but felt strongly that such investigative activities were good for the personnel involved. The Region held that local studies by Forest Officers were excellent training for forest personnel to develop their skills and knowledge of the resources, as well as their interest in use and management.

⁴Storey, H. C. *History of Forest Service research: Development of a national program.* (A working report, dated Apr. 24, 1975, on file at USDA For. Serv., Washington, D. C.)

⁵U.S. Forest Service, *District 2 Investigations: Reports and Programs.* (On file, Library, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)

Observations and investigations were undertaken in many aspects of timber management, grazing management, and watershed management (chiefly erosion and streamflow). Investigations in timber management included growth studies, seeding habits, natural reproduction, seeding and planting, logging slash disposal, harvesting methods, logging practices, and forest fire. A network of permanent sample plots in the main timber types—ponderosa pine, lodgepole pine, and Engelmann spruce—was established, and re-measured periodically to obtain the above information under various site, harvesting, and natural conditions.⁶

Grazing management observations and investigations included plant identification, plant growth and development, poisonous plants, natural revegetation, reseeding, forage production and utilization, degree and seasons of use, handling of livestock, and wildlife observations.

In watershed management, such occurrences as erosion, floods, and time and amount of streamflow under various conditions were observed.

Fremont Experiment Station

The principal field base and laboratory of the forest investigations in Region 2—the Fremont Experiment Station established September 3, 1909—was located near Manitou Springs, Colorado, in a pleasant mountain valley on the east slope of Pikes Peak, Pike National Forest. Here the principal forest types of the Region were represented, and the Station was so located "because it combined remoteness to insure a favorable atmosphere for carrying on various phases of research within the more important timber types (Engelmann spruce, ponderosa pine, Douglas-fir) indigenous to the Rocky Mountain Region."⁷ In those days the automobile was a luxury and forest administrators were not thinking in terms of highway accessibility. Access to the Station was by tram, with horse and wagon between the upper terminals of the tram and the headquarters.

⁶*It is not the purpose of this publication to enumerate and describe all investigations or research undertaken. These are on file. Only fields of investigations and studies that show the direction and history are included. Moreover, not all forest officers and scientists are included; only those who had a part in initiating or directing the work are mentioned. A list of research personnel, taken from available records, is included in the appendix.*

⁷Roeser, J., Jr. 1955. *A brief chronological history of the Rocky Mountain Experiment Station.* (Typewritten report, Apr. 18, 1955, on file, Library, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.)



Carlos G. Bates, one of the pioneer silviculturists of the Forest Service (Forest Examiner) who was assigned to Region 2, located and established the Fremont Station, which was named after General John C. Fremont, a noted explorer. Dr. Frederick E. Clements, pioneer ecologist, then director of the Alpine Laboratory of the Carnegie Institute (nearby on Ruxton Creek, Minnehaha Falls), accompanied Bates in establishing the Station.



(Right) Carlos G. Bates, Forester in Charge, Fremont Experiment Station, Colorado, 1909-27. (Left) Bates, in third seat from top, rides the Manitou Incline (courtesy of Verne C. Fuhlrodt).



Carlos G. Bates, with first load of supplies brought in on four wheels to the Fremont Experiment Station, Colorado, 1917.

Bates⁸ was one of several University of Nebraska forestry graduates who played a prominent role in the early history of Forest Service research.⁹ Following his graduation with a B.S. degree in 1907, Bates received an appointment as forest assistant in the Forest Service at a salary of \$1,000 per annum. Bates was one of a group of young foresters who suggested to Chief Forester Pinchot the need for forest experiment stations. He was assigned the project of establishing a station within the Central Rocky Mountain District.

Bates was the principal investigator at the Fremont Station from 1909, the time of its establishment, until July 1927 when he transferred to the newly created Office of Biological Research at the Forest Products Laboratory. Within a year he transferred to the Lake States Forest Experiment Station. In 1934 he was assigned to provide

⁸Roeser, Jacob, Jr. 1956. Carlos Glazier Bates: Pioneer silviculturist, 1885-1949. *J. For.* 54(4):272-273.

⁹Others include G. A. Pearson, R. R. Hill, A. W. Sampson, A. T. Upson, Paul Roberts, J. S. Boyce, E. W. Nelson, C. L. Forsling, and W. R. Chapline.

technical guidance to the Great Plains Forestry Project (Shelterbelt Program).

Bates literally built the Fremont Station and its facilities. In addition to giving technical guidance to administrative studies by Region 2 forest officers, Bates completed many important investigations, several of which received national attention.

Bates started an arboretum and carried on a program of exotic tree introductions. Seeds were collected and tested in a study to determine the amount of periodicity of seed production of Rocky Mountain conifers in relation to climatic conditions, flowering, and cone production. Several plantations were established to determine the practical significance of geographic varieties and hereditary character of individual variation. Bates early recognized the significance of seed sources in forest planting. Another project of fundamental character, begun in 1910, was a study to determine the limiting climatic and edaphic factors affecting the distribution of forest types.

Prior to 1920, the office for the Fremont Station was in the Forest Service Regional Office

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In 1911, Bates evaluated windbreaks planted in the late 1800's. The mulberry hedge in Colorado's Arkansas Valley and the Lombardy poplars in Mesa County were used to protect orchards from wind and drifting sand.





Fremont Experiment Station, Colorado, 1920.

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in Denver. From 1920 until the late summer of 1935 when the Station was closed,¹⁰ offices were in quarters with the Pike National Forest in Colorado Springs.

The Fremont Station was renamed in 1925 to the "Rocky Mountain Experiment Station" which better characterized its work.

When Bates left the Station in 1927, Jacob Roeser, Jr., Bates' assistant, carried on the work of the Station. Roeser worked under the Chief of Timber Management of the Region, and continued the work started by Bates. When the Station closed in 1935, Roeser joined the newly established Rocky Mountain Forest and Range Experiment Station, with headquarters at Fort Collins, Colorado. Later, 1936, Roeser transferred to forest administrative work with Region 2.

In February 1953, during their annual meeting, the Central Rocky Mountain Section of the Society of American Foresters voted to commemorate the career and the pioneer contributions of Carlos G. Bates to forestry research by dedicating the plantations at the old Fremont Experiment Station, which he founded, to his name.

¹⁰In 1945, all improvements, including the fence, were sold. Dismantling was completed in 1947.

J. Roeser, Jr., observing ponderosa pine cones for drying. Fremont Experiment Station, Colorado, 1924.



**Wagon Wheel Gap Experiment:
A Milestone in Watershed
Management Investigations**

One of the purposes for establishing the National Forests was watershed protection and regulation of streamflow. With the several major rivers in the Central Rockies originating within the National Forests, the matter of streamflow and the effects of forest cover on runoff and erosion and watershed protection was of early concern. No specific information in this field existed in the United States. The one and only serious attempt to measure the influence of forests upon streamflow was the Emmmenthal study in Switzerland.¹¹

¹¹Engler, Arnold. 1919. [Experiments showing the effect of forests on the height of streams.] 626 p. Mitt. Schweiz. Centralanst. Forstl. Versuchswes. XII, Zurich. (As cited in Bates, Carlos G., and Alfred J. Henry. 1922. Streamflow experiment at Wagon Wheel Gap, Colorado. Mon. Weather Rev. Suppl. 17, 55 p.)

Acting on the instructions from the Washington Office, a search was made for watersheds suitable for a study of the effects of forest cover on streamflow and erosion. The plan was "to select two contiguous watersheds, similar as to topography and forest cover; to observe carefully the meteorological conditions and the streamflow for a term of years under similar conditions of forest cover; then to denude one of the watersheds of its timber and to continue the measurements as before for an indefinite period, or until the effects of the forest destruction upon the time and amount of streamflow, the amount of erosion and quantity of silt carried by the streams had been determined."¹²

In 1910, Henry S. Graves, Chief Forester, stated "To determine exactly what effects the forest cover may have upon the disposition of rain and snow water, its runoff storage, and later

¹²Bates, Carlos G., and Alfred J. Henry. 1922. Streamflow experiment at Wagon Wheel Gap, Colorado. Mon. Weather Rev. Suppl. 17, 55 p.



Wagon Wheel Gap experimental watersheds, Colorado, 1911. Circles indicate weir locations.



Measuring snow conditions on watershed B, Wagon Wheel Gap, Colorado, 1911.

appearance in springs, and the possibility of erosion and silting up of streams, an experiment station has been started at Wagon Wheel Gap, on the Rio Grande National Forest. . ."¹³

"Since the plan of the experiment contemplated the use of considerable instrumental equipment and the services of men skilled in meteorological observations, the cooperation of the Weather Bureau was solicited, and on approval of the Secretary of Agriculture, the two services began the active work of getting material and equipment on the ground on June 1, 1910."¹²

Bates, Nile Hughel, surveyor, and C. R. Tiltonson were on the site June 1, 1910, to represent the Forest Service. Forest Assistant P.T. Coolidge, Rio Grande National Forest, found the water-

sheds to be studied. Bates, with the occasional aid of several Forest Service men, completed the layout of the experimental watersheds and handled the Forest Service part of the work. The Wagon Wheel Gap study area was handled as a Branch of the Fremont Station.

Like many pioneer research efforts, the Wagon Wheel Gap Experiment raised more questions than it answered. This, as has been learned since, was largely because of the design of the experiment. It would have been interesting and no doubt fruitful if the treatment could have been reversed on the watersheds and run for another time period, which would have provided the replication so vital in experimental work. Nevertheless, the experience gained and the information and results obtained have been benchmarks for subsequent watershed research undertakings.

¹³U.S. Forest Service. 1910 Annual Report.

Grazing Investigations

Grazing studies began early. L. H. Douglas was assigned to Region 2 in 1911 as Grazing Examiner. Later Chester Lee and H. E. Schwan joined Douglas in conducting the administrative range studies. Some of the principal areas of observation and study included plant identification, natural revegetation, reseeding, and range utilization. Douglas also compared the open-herding and bedding-out system of sheep grazing to the sheep grazing system then prevalent.

Region 3 Investigations

Forest investigations in Region 3 (Arizona and New Mexico) followed much the same pattern as in Region 2, but pertained mostly to ponderosa pine, the principal timber species in the Southwest. One of the main reasons the Fort Valley Experiment Station was established and located in the Southwest was to study the reproduction of ponderosa pine and how to get more trees established.

On many areas of the Coconino National Forest, one could see through the ponderosa pine forests for great distances because of the limited and low growing pine reproduction. Uncontrolled forest fires in early years, drought, and browsing by livestock, mainly sheep, as the result of unregulated grazing, contributed to the scarcity and injury to the pine reproduction.

Largely because of weather and growth conditions, reproduction of ponderosa pine occurs infrequently. In dry years much of the reproduction that did occur was damaged by browsing animals, especially in heavily grazed areas. But the favorable amount and timing of precipitation in 1919 plus a bumper seed crop that fell on a seedbed with reduced competing vegetation, resulted in much reproduction. About this same time sheep and cattle numbers were reduced. As a result, the ponderosa pine stands became thick with reproduction, much too thick in many places. This reproduction is now furnishing the growing stock for the forests.

Fort Valley Experiment Station

The Fort Valley Experiment Station was the main field station and laboratory for forest management investigations in Region 3. G. A. (Gus) Pearson, another pioneer silviculturist (Forest Examiner) assigned to Region 3 was the principal forest investigator at the Fort Valley Station and remained until his retirement in 1945.

Rare is the scientist that remains in the same field of investigation at the same location during his lifetime. Pearson was one of them. He spent his entire career studying ponderosa pine in the Southwest. After his retirement in 1945, Pearson continued as an unofficial collaborator working on and writing up his findings. At the time of his death, January 31, 1949, he was at his desk at

"Pink" mules used to haul freight and visitors to Fort Valley Experiment Station, Arizona, 1910.





G. A. "Gus" Pearson, Forester in Charge, Fort Valley Experiment Station, Arizona, 1908-30.

the Southwestern Forest and Range Experiment Station headquarters on Tumamoc Hill in Tucson, Arizona. His head rested on his manuscript which became his now-famous monograph, "Management of Ponderosa Pine in the Southwest" (Agric. Monogr. 6).

As with Bates, the Forest Service and the Government got their money's worth out of Pearson. Pearson not only pioneered and conducted the work at Fort Valley but he also was the stimulus to the early administrative forest studies in Region 3. He trained and worked with many associates who helped at one time or another to carry on the research program at Fort Valley. The list includes many who would be prominent in a "Who's Who" in American forestry. Some of those who worked at Fort Valley with Pearson, more or less in chronological order, include: J. S. Boyce, Max H. Foerster, Harold H. Greenamyre, Alexander J. Jaenicke, Norman W. Scherer, Enoch W. Nelson, Clarence F. Korstian, M. W. Talbot, R. D. Forbes, Herman Krauch, Harold S. Betts, Joseph C. Kircher, Emanuel Fritz, Ferdi-

nand W. Haasis, Bert Lexen, E. M. Hornibrook, E. C. Crafts, Elbert H. Little, Jr., Frank W. Wadsworth, and George S. Meagher.

Pearson was enthusiastic about his work; it was always uppermost on his mind. Like Bates, Pearson was a keen observer. Each made extensive, close, and repeated observations which made up for the lack of formal replication in their studies. Pearson knew intimately each tree that grew at Fort Valley! On one occasion he stopped his trusty Ford coupe, got out, and rolled away a rock that was resting against a young ponderosa pine with the comment, "These cursed road builders have no regard for value or beauty!"

In 1950, the Southwestern Section of the Society of American Foresters, assembled at Flagstaff, Arizona, dedicated the 154-acre natural area of ponderosa pine at Fort Valley as the "G. A. Pearson Natural Area"—a living memorial to the man and his work.

Hermann Krauch, a long-time associate of Pearson, was paid by the Region but worked closely with Pearson in ponderosa pine investigations. Krauch completed several individual tree studies of ponderosa pine, and conducted investigations of Douglas-fir at the Cloudcroft Experimental Forest in southern New Mexico. He established the spruce plantings on the Santa Fe National Forest, which stand as a memorial to him.

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Hermann Krauch, R. D. Forbes, and M. W. Talbot, ready for a day of plot mapping. Fort Valley Experiment Station, Arizona, 1913.



Grazing Investigations

Grazing investigations also began early in Region 3—soon after the establishment of the National Forests. They were administered by the Office of Grazing and were conducted throughout the Region. Some of the principal areas of observation and investigation included plant identification, natural revegetation, reseeding, range utilization, grazing damage to pine reproduction, use of water and salt, use of shrub ranges, and indicators of range use.



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D. A. Shoemaker checks blue grama range near boundary of Manzano National Forest, New Mexico, 1921.

Those who played a prominent role in regional grazing investigations included R. R. Hill, Grazing Examiner, who was assigned to Region 3 in 1911 in charge of the Regional Office of Grazing Studies. An important contribution by Hill was information about grazing and pine reproduction. M. W. Talbot, also a member of the Regional Office of Grazing Studies (and in charge from 1920 when Hill took charge of the Santa Rita Range Reserve), published information regarding the use of salt and watering places in range management, and the classic handbook, "Indicators of Southwestern Range Conditions" (Farmer's Bull. 1782). Talbot established the first plots for studying grazing and erosion on the Tonto National Forest. C. K. Cooperrider, who also reported findings regarding grazing use and damage to pine reproduction, carried forward the erosion and watershed investigations chiefly centered in the Salt River Basin in Arizona.

Santa Rita and Jornada Range Reserves

In 1915, the Santa Rita and Jornada Range Reserves were transferred to the Forest Service from the former Bureau of Plant Industry, U.S. Department of Agriculture. With these transfers, responsibility for range (native pasture) research in the Department of Agriculture on public and private lands passed to the Forest Service. The Santa Rita and Jornada Range Reserves, later called Experimental Ranges, became the centers for the study of the vast semidesert ranges of the Southwest. General direction of the investigations on these areas was by the Office of Grazing Studies in Washington, D. C., headed by James T. Jardine until 1920 and then by W. Ridgely Chapline, who later became the first Chief of the Division of Range Research.

The **Santa Rita Range Reserve**, located in southern Arizona near Continental, was established in 1903 by the Bureau of Plant Industry. David Griffith, Assistant in Charge of Range Investigations Office of Grass and Forage Investigations, Bureau of Plant Industry, selected the area. Santa Rita, the oldest experimental range in the United States, was enlarged in 1907, and consists of about 51,000 acres typical of much of the semidesert grass and shrub rangelands in southern Arizona, southern New Mexico, and west Texas.



Headquarters, Santa Rita Experimental Range, Arizona, 1926.

When the Range Reserve was placed under the jurisdiction of the Forest Service in 1915, a range research program was begun with two major objectives: (1) to determine the best way to manage the lands in order to restore, improve, and maintain them at a sustained basis of productivity; and (2) to determine methods of handling cattle on the range to obtain the greatest returns over a period of time. Many and varied studies were conducted toward these objectives, and have greatly benefited the users and managers of these rangelands.

C. E. Fleming was responsible for both the Santa Rita and Jornada Range Reserves for the Forest Service. R. L. Hensel was the first Director of the Santa Rita. R. R. Hill followed Hensel in 1920. Hill was followed by Matt J. Culley in 1921. Culley worked closely with the range livestock producers, and is noted for his range and range livestock photography.

C. T. Vorhies, University of Arizona, and Walter P. Taylor, U.S. Biological Survey, made extensive studies of kangaroo rats and jackrabbits. Storage of mesquite seeds in mounds by the kangaroo rats was a factor in the spread of mesquite, and the jackrabbits competed with livestock for forage. During the early 1930's, cooperative studies with the University of Arizona by A. A. Nichol and others furnished deer feeding information; also water requirement information of important range plants was supplied by W. G. McGinnies and J. F. Arnold.

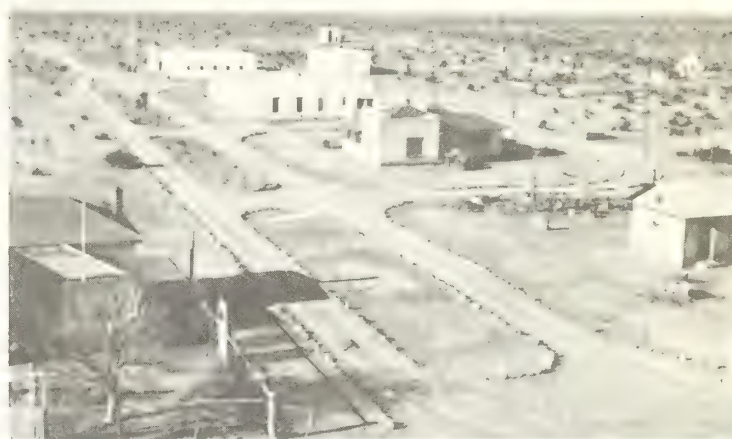
The Desert Grassland Station was established on the Santa Rita Experimental Range in cooperation with the University of Arizona. W. G. McGinnies and L. D. Love were in charge for the University. This activity on the part of the University was a reflection of the interest of the President, H. L. Shantz, who later was in charge of Wildlife Management for the Forest Service.

In the late 1940's, additional intensive studies were started on the Santa Rita. These included range reseeding, noxious plant control, and ecological investigations including, in 1970, the use of part of the area as a validation site for part of the Desert Biome of the International Biological Program. Those who took the lead in conducting and directing these activities, in chronological order, were G. E. Glendening, H. G. Reynolds, and S. C. Martin (1955 to present). Many other investigators in range management and range wildlife including range rodents, have worked on the Santa Rita; also many forestry and other students have visited and studied the area.

The Jornada Range Reserve was established by Executive Order in 1912 with E. O. Wooten, Bureau of Plant Industry, in charge. The Range

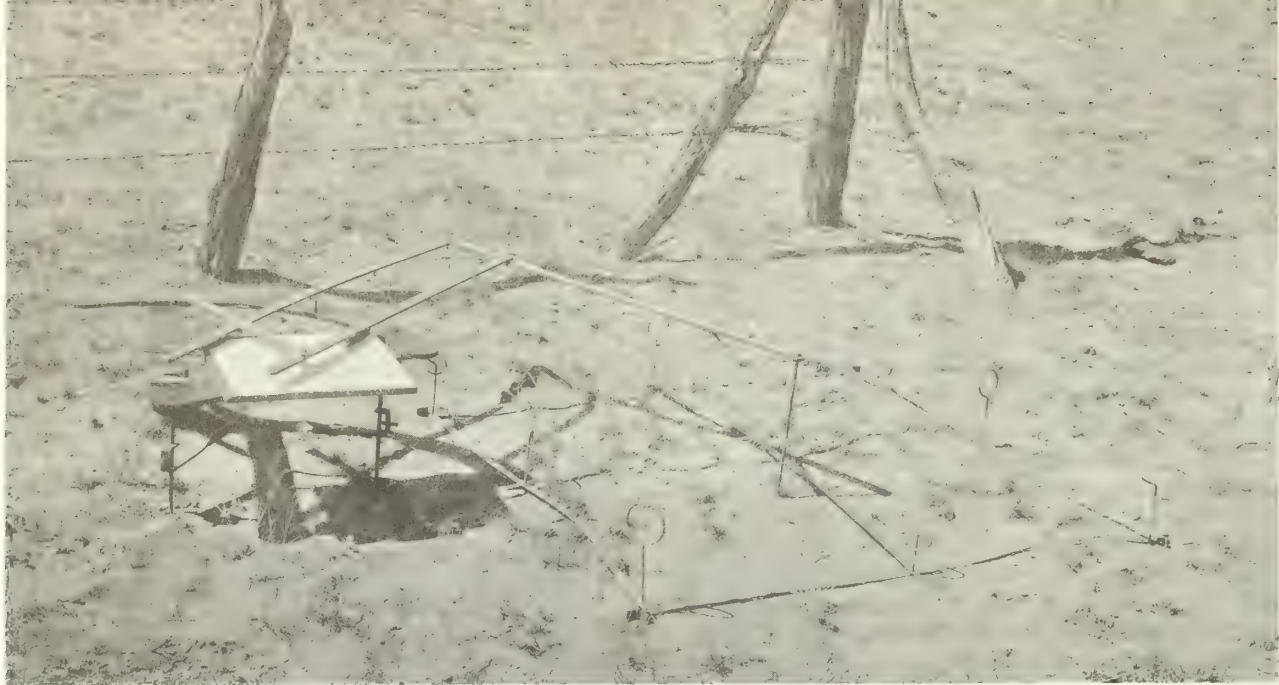
covered 193,394 acres, most of it on the Jornada Del Muerto Plain in Dona Ana County, New Mexico. The east side, which extended into the San Andreas mountains, was later withdrawn for part of the White Sands bombing range. The Jornada is also classed as semidesert range, and includes black grama grasslands, tobosa flats, creosotebush-tarbrush types, and mesquite sandhills, typical of extensive rangelands in southern New Mexico, west Texas, and southern Arizona.

The main objectives of the Jornada were similar to those of the Santa Rita—how to improve and maintain the range, and how to manage it for sustained use and production of range livestock. Drought and its effects are critical on this type of range.



Headquarters, Jornada Experimental Range, New Mexico, 1934.

C. E. Fleming was the first Director of the Jornada Experimental Range for the Forest Service in 1915. L. C. Hurtt directed the work in 1916. C. L. Forsling became Director in early 1917, and remained until late in 1920. E. W. Nelson took charge in 1920, and remained until 1924. Nelson was followed by J. D. Schoeller until 1927 at which time R. S. Campbell was assigned in charge. In 1931, F. N. Ares was assigned as Superintendent. Many range scientists, range administrators, and students have visited and studied at the Jornada Experimental Range. Also, Ranch Day, held annually for several years in cooperation with New Mexico State University to show and present the work at the Jornada and



R. R. Hill's pantograph, set up for measuring black grama quadrat. Jornada Experimental Range, New Mexico, 1924.

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the adjacent "College" Ranch, was attended by many stockmen, extension specialists, range scientists, range administrators, students, and interested public. In accordance with the November 2, 1953 memorandum issued by Ezra Taft Benson, Secretary of the U.S. Department of Agriculture, the Jornada Experimental Range was transferred to the Agricultural Research Service, January 1, 1954.

The Santa Rita and Jornada Experimental Ranges, as developed by the Forest Service, are unique experimental areas. The lands and improvements are owned by the Federal Government.

The cattle grazing the Ranges are owned and managed by operating stockmen under a plan of management outlined in a cooperative agreement with the Government. The stockmen graze their cattle throughout the year on the Range in designated pastures according to a management plan. Hence, the facts and information obtained about the range and the cattle grazed thereon, are directly applicable to range livestock operations with little or no extension or modification. In contrast, results obtained from plot or small fenced-pasture studies have to be extended or modified.

Yearling steers from Jornada Range Reserve, New Mexico, ready for sale at \$27 per head at the railroad, 1913.



Complexity of Forest Land Management Called for Organized Research

Early forest investigations provided some needed guidance in use and management of the National Forests. Also, administrative studies contributed to some extent to local use and management. But, the complexity of forest land use and management soon dictated the need for more fundamental, continuous, and correlated research. Thus, in 1915, the Forest Service established the Branch of Research, headed by Earle H. Clapp, Assistant Chief. The research activities of the Forest Experiment Stations, the Forest Products Laboratory, and the Washington Offices of Products and Silviculture were placed under this new Branch of Research. Included in the Experiment Stations were those in the Central and Southern Rocky Mountain Regions, namely, Fort Valley at Flagstaff, Arizona, and Fremont and Wagon Wheel Gap in Colorado. The newly acquired Santa Rita and Jornada Range Reserves in southern Arizona and southern New Mexico continued under the supervision of the Washington Office of Grazing Studies in the Branch of Grazing until

1926 at which time they also became a part of the Branch of Research.

As the importance and use of forest land resources further increased, the Forest Service recommended the creation of a nationwide forest-research program¹⁴ consisting of one forest experiment station for each of the 12 major timber regions of the United States. On May 22, 1928, the U.S. Congress passed the McSweeney-McNary Act which authorized the establishment of the 12 regional forest experiment stations.

Two years later, in 1930, Congress appropriated funds for the establishment of the Southwestern Forest and Range Experiment Station. In 1935, funds were appropriated for the establishment of the Rocky Mountain Forest and Range Experiment Station. As discussed later, these two Stations were combined in 1953.

¹⁴U.S. Department of Agriculture. Forest Service. 1933. *A national plan for American forestry*. U.S. Sen. Doc. 12, 73d Congr., 1st Sess., 2 vols., Gov. Print. Off., Wash., D.C.



The Southwestern Forest and Range Experiment Station, 1930-53

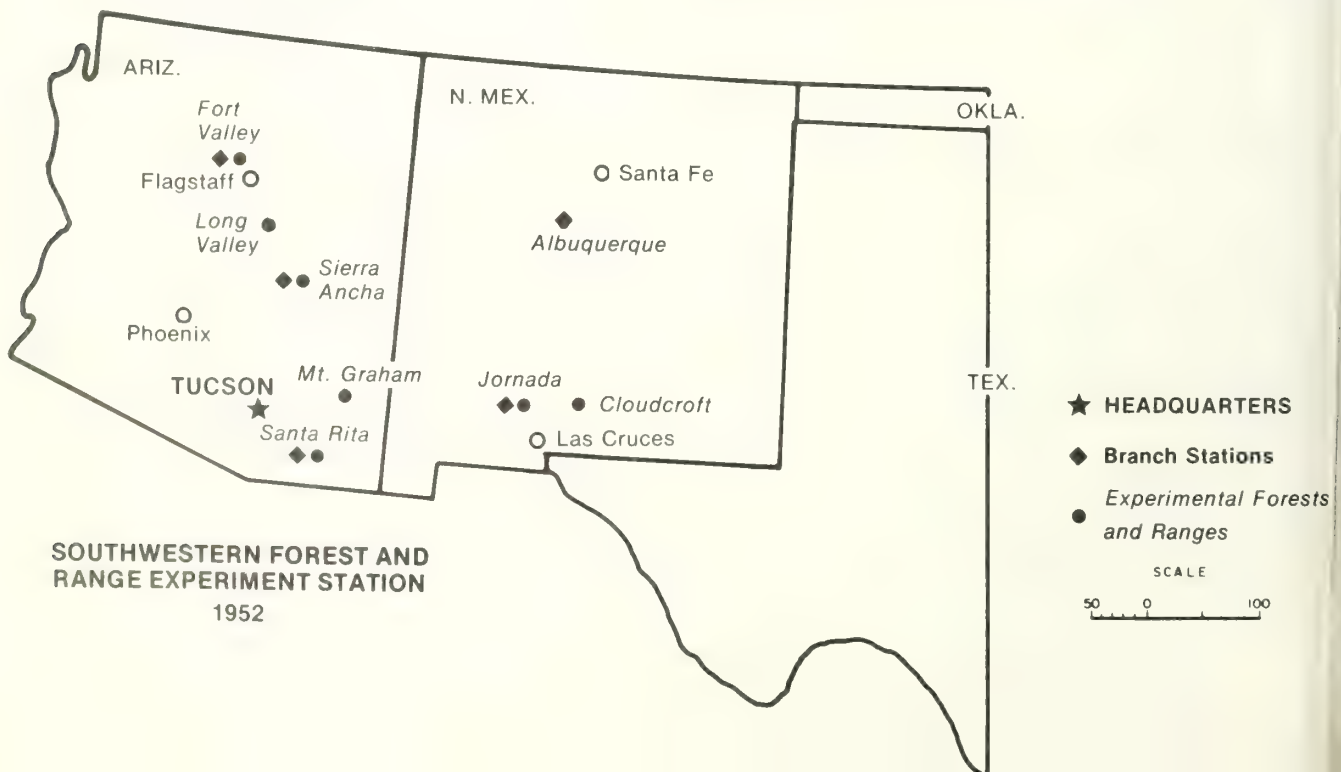
The Southwestern Forest and Range Experiment Station was established August 1, 1930, as a regional research unit of the Forest Service, U.S. Department of Agriculture. The general function of the forest and range experiment stations was to do the research that would aid in solving the forest and range problems of the nation. The specific research problems on which each station engaged varied according to the needs of the region that a particular station served. Many of the problems were common to more than one region, but by interchange of ideas and results among stations, solutions were obtained more rapidly than might be possible otherwise. Also, the Congressional Act creating the experiment stations did not restrict activities to National Forest problems, but required that the experiment stations work on nonagricultural forest and rangelands outside the National Forests. The forest experiment stations thus complemented the work of the State agricultural experiment stations which, at that time, worked primarily on farming lands.

The territory covered by the Southwestern Station comprised the States of Arizona, New Mexico, approximately the western half of Texas, and the Panhandle of Oklahoma.

The broad objective of the Station was two-fold:

1. To add and improve upon existing knowledge of timber, range, and watershed management; and
2. To furnish answers to technical and practical problems arising in the administration of National Forests in Region 3; those confronting private owners of timber, range, and watershed lands in the Southwest, and to varying degrees, other Federal and State agencies.¹⁵

¹⁵U.S. Department of Agriculture. Forest Service. 1936. Annual report on progress in research for calendar year 1935 and recommended program of research for fiscal year 1936-37. 105 p. Southwest. For. and Range Exp. Stn., Tucson, Ariz.

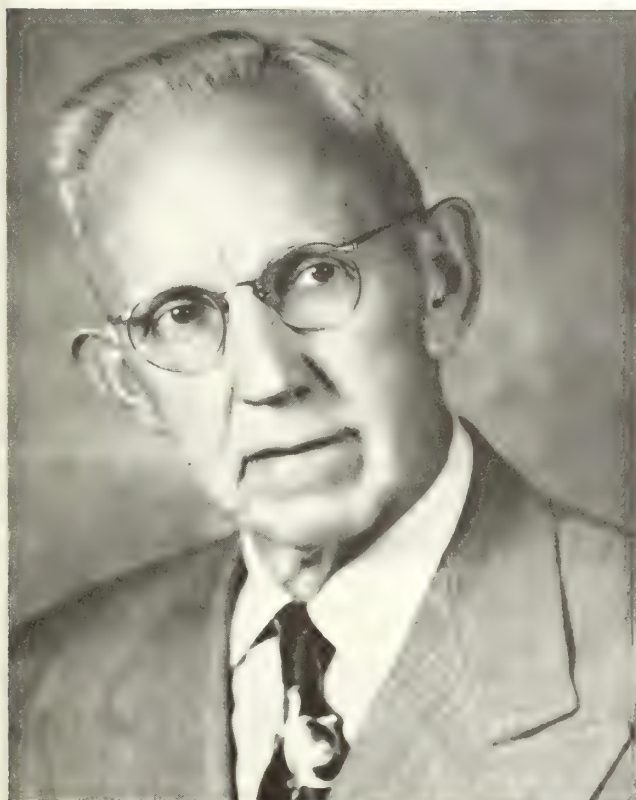


***Directors,
Southwestern Forest and Range
Experiment Station, 1930-53:***

G. A. Pearson, 1930-35



Arthur T. Upson, 1935-42



Raymond Price, 1942-53



The Station's headquarters was located at Tucson, Arizona, and, under a cooperative agreement with the University of Arizona, was officed on the top floor of the Agriculture building on the University of Arizona campus.

The establishment of the Southwestern Forest and Range Experiment Station brought together in one organization the Fort Valley Forest Experiment Station, the timber management research at Cloudcroft, the range research on several National Forests, the erosion and watershed research on the Tonto National Forest (Parker Creek), and the Santa Rita and Jornada Range Reserves. These major units became field laboratories (Experimental Forests, Watersheds, and Ranges) under the new Southwestern Station.

The work of the Station was organized under three major lines of investigation, namely: Timber Management (Silvical), Forest and Range Influences (Watershed Management), and Range Management. G. A. (Gus) Pearson was named Director of the Station and in charge of Timber Management Research. C. K. Cooperrider was in charge of Watershed Management Research and Range Management Research. Matt J. Culley was in charge of the Santa Rita Experimental Range, and R. S. Campbell was in charge of the Jornada Experimental Range.

Funds available in FY 1931 totaled \$57,181.59, and were made up as follows:¹⁶

Timber Management

Silvical Investigations	\$ 9,900.00	
Management—National Forests	7,736.00	\$17,636.00
Watershed Management		5,000.00
Range Management:		
Range Research on National Forests—		
Range Investigations	11,600.00	
Management—National Forests	2,600.00	14,200.00
Santa Rita Experimental Range—		
Range Investigations	11,600.00	
Coop Fund (Cooperating Stockmen) ...	571.80	12,171.80
Jornada Experimental Range—		
Range Investigations	7,000.00	
Coop Fund (Cooperating Stockmen) ...	1,173.79	8,173.79
Total budget, fiscal year 1931		\$57,181.59

Fields of Research

Research in **Timber Management** was organized and conducted under the following major lines of work (listed in order of expenditure of funds): management—ponderosa pine; management—Douglas-fir; thinning—ponderosa pine; forestation and management—Engelmann spruce. **Watershed Management** research was centered on shrub associations in Arizona. **Range Investigations** included: management of bunchgrass in cutover pine forest; management of black grama and associated species (Jornada); management of semidesert mixed grasses (Santa Rita); handling livestock on the range; and management of browse range.

In 1931, **Forest Mensuration** research was begun by B. R. Lexen who also conducted other Timber Management research. A special project undertaken by Cooperrider with assistance of B. A. Hendricks was the Elephant Butte Watershed Survey of the Rio Grande in New Mexico. The upper part of the watershed in Colorado was handled by Forest Supervisor J. Higgins of Region 2.

Two additional field units were established in 1932, namely: The Parker Creek Erosion-Streamflow Station (later named Sierra Ancha Experimental Watersheds) above Roosevelt Dam on the Tonto National Forest in central Arizona,

Organization of the Southwestern Forest and Range Experiment Station, 1930¹⁶

Director: G. A. Pearson

Timber Management

G. A. Pearson, in charge

Hermann Krauch

E. M. Hornibrook

Fort Valley Branch Station—

W. J. Osborn

Watershed Management:

C. K. Cooperrider, in charge

Range Management:

C. K. Cooperrider, in charge

B. A. Hendricks

H. O. Cassidy

E. S. Bliss

Santa Rita Experimental Range—

M. J. Culley, in charge

P. B. Lister

Jornada Experimental Range—

R. S. Campbell, in charge

R. H. Canfield

¹⁶U.S. Department of Agriculture. Forest Service. 1931. Annual Report, Southwestern Forest and Range Experiment Station, 1930.



Headquarters, Santa Rita Experimental Range, Arizona, 1936.

and the Mt. Graham Experimental Forest near Safford, Arizona. B. A. Hendricks was given charge of Parker Creek, and H. O. Cassidy was given charge of Range Research on the National Forests, under the supervision of Cooperrider.

During the early 1930's, emergency funds became available in connection with the National Industrial Recovery Act (NIRA), Works Progress Administration (WPA), and the Civilian Conservation Corps (CCC). These emergency programs, made available to stimulate employment, were used by the Station to advance forestry research and made it possible to undertake research in following years which otherwise would not have been possible. Roads, telephone and power lines, and housing and physical research facilities were built. Also, various experimental land treatments such as reforestation, timber stand improvement, and soil erosion and range surveys were accomplished. Additional technical help, financed from these emergency funds, also made it possible to obtain, compile, analyze, and publish helpful information.

Considerable help was furnished by the CCC in conducting a study in the woodland type to determine methods of managing this extensive forest type. The study was in cooperation with the Forest Products Laboratory and the Division of Forest Pathology of the Bureau of Entomology and Plant Quarantine. B. R. Lexen designed the study, and G. L. Meagher and E. L. Little, Jr. conducted the research and reported the results.

Expanded Research Accompanying Aggressive Public Action Programs

With the stimulus of the increased funding from the various emergency programs which made possible the construction of research facilities, the Station was in a position to contribute technical know-how and assistance in several areas of forest and range land management. This was facilitated by reorganization and additions to the Station. Beginning in 1935, Director Pearson returned full time to management of ponderosa pine at Fort Valley. It became possible for him to complete studies for his ponderosa pine monograph.

Arthur T. Upson was appointed Director of the Station. Upson graduated in forestry from the University of Nebraska. He joined the Forest Service as a technical timber assistant, Arapaho National Forest in 1910, and filled various assignments in administration of the National Forests and at the Forest Products Laboratory. In 1924 he left the Forest Service and was employed by the National Lumber Manufacturing Association until returning in 1935 as Director of the Station. With his enthusiasm and managerial skills, Upson pulled the Station together into an overall productive unit. He intensified the research at the Jornada and Santa Rita Experimental Ranges and the watershed studies at Sierra Ancha.

Desert Grasslands Station on Santa Rita Experimental Range, Arizona, Mid-1930's.





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Key buildings at Fort Valley Experimental Forest, Arizona, 1915:

- A, Laboratory and office.**
- B, Caretaker's house.**
- C, Cone-drying shed.**
- D, Pearson's residence, built in 1909.**

E. C. Crafts measures ponderosa pine growth on experimental plot. Fort Valley Experimental Forest, Arizona, 1935.

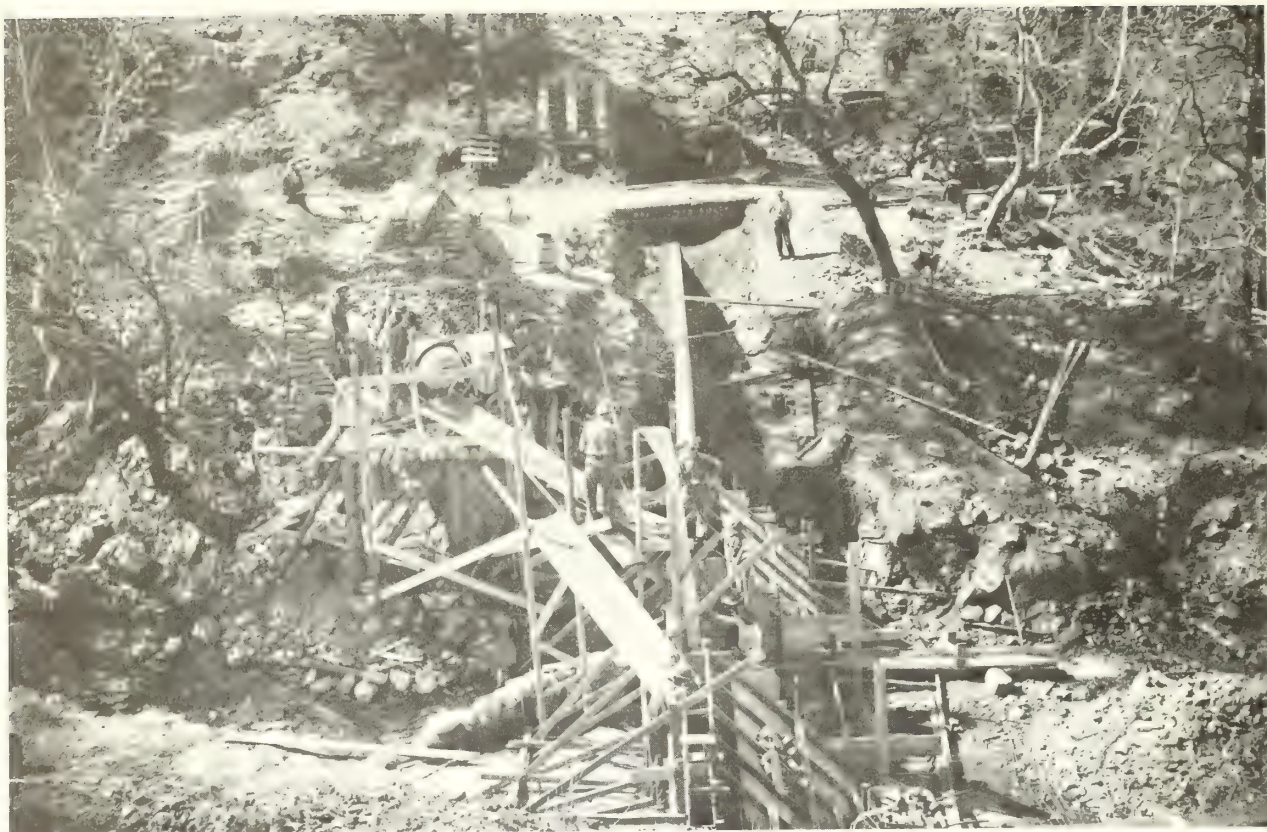




Additional key personnel were added, several of whom later filled more responsible positions in the Forest Service. Among these were E. C. Crafts, K. W. Parker, G. E. Glendening, W. G. McGinnies, G. S. Meagher, Frank Wadsworth, and E. L. Little, Jr. Crafts later became Associate Chief of the Forest Service and was the first Director of the new Bureau of Outdoor Recreation, U.S. Department of the Interior. Parker became Division Chief of Range Research at the Station and subsequently Chief, Division of Range Research for the Forest Service in Washington, D. C. Glendening headed up several research projects and was a Project Leader at the Station at the time of his untimely death. McGinnies was in charge of Range Research at the Station and then went on to become Director of the Rocky Mountain Station and Director of the Central States Station. Meagher became Chief, Division of Forest Management Research at the Station and then filled the same position at the Pacific Northwest Station. Wadsworth is Director of the Institute of Tropical Forestry, Puerto Rico. He is the recognized authority in Tropical Forestry. Little became the Dendrologist for the Forest Service.

Headquarters, Parker Creek Erosion-Streamflow Station, Arizona, 1935. (Later called Sierra Ancha Experimental Watersheds.)





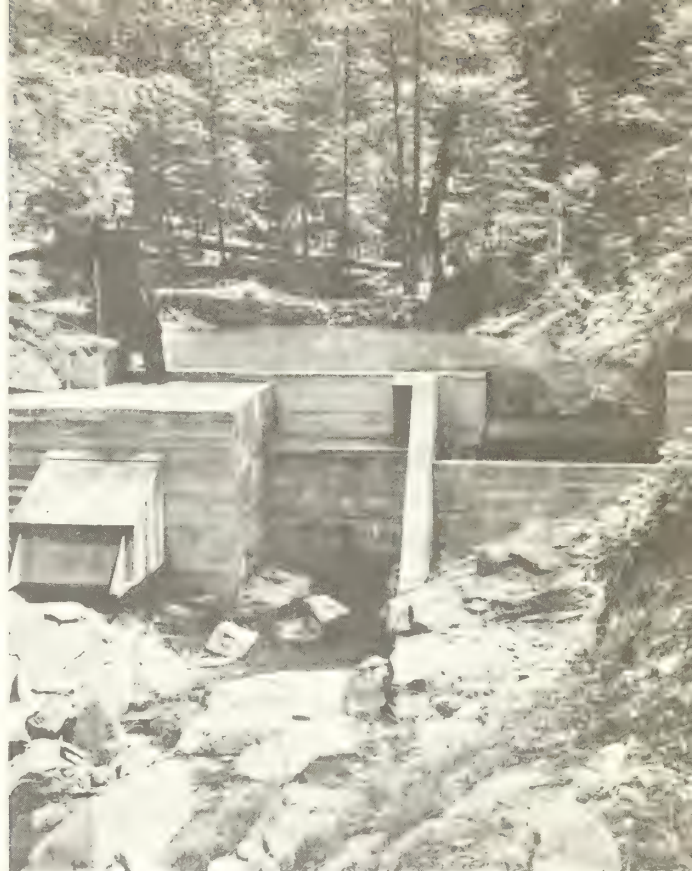
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◆ *Civilian Conservation Corps constructs dam and weir for watershed research on Upper Pocket Creek. Sierra Ancha, Arizona, 1936.*

◆ *Weighing transpiration can during evapotranspiration experiment at Sierra Ancha, 1937.*

◆ *Compound weir on Workman Creek, for measuring streamflow changes after timber harvest. Sierra Ancha Experimental Forest, early 1940's.*



Several significant lines of research were begun and land use measures accomplished during the late thirties. In 1937 the cooperative Range Utilization Standards studies were begun. R. S. Campbell directed the work Servicewide. E. C. Crafts, G. E. Glendening, and B. A. Hendricks actively participated. Formal Shrub Invasion Control research was begun by K. W. Parker. The Station was an active participant in Flood Control Surveys under the Omnibus Flood Control Act of June 22, 1936, cooperating with the Soil Conservation Service, Bureau of Agriculture Economics, and Corps of Engineers of the U.S. Army. Cooperrider was in charge of the work assisted by W. W. Wier, E. S. Bliss, H. O. Cassidy, B. Nelson, and G. G. Sykes. This work continued into 1941. The Station also participated in the Western Range Survey in cooperation with the Agriculture Adjustment Administration under the Agriculture Adjustment Act. The work was handled by G. D. Merrick, E. S. Bliss, E. W. Bomberger, and K. W. Parker. The work was completed in August 1938.

The Long Valley Experimental Forest was formally established in 1937. This area was a virgin stand of high-site ponderosa pine. Except for growth data, the area was never fully used experimentally because of lack of funds; also, mining activities destroyed most of one section.

In 1940, the Station, under agreement with Region 3, gave impetus to the collection of essential range resource data on the Range Study Plots located throughout the Region. The goal was the establishment of a minimum of one study plot within each major vegetation type on each Ranger District. The effort did not fall much short of the goal! The original records included writeups of the vegetation, photographs, and detailed sampling of a 100- by 100-foot plot within each fenced enclosure and of a similar sized plot on comparable adjacent grazed areas. These data have not only furnished helpful information on range recovery, range utilization, and range condition and trend, but—if the areas are safeguarded and the records are maintained—valuable benchmarks of range conditions and use can be obtained for time to come.



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Invasion of mesquite as the result of drought, planting of seeds by kangaroo rats, and heavy grazing. Santa Rita Experimental Range (upper) 1903; (lower) 1941.

Headquarters

With the growth of the Station and the expansion of the University of Arizona, it became necessary for the Station to move its headquarters off campus. The Station rented an apartment house in the 700 block on Third Avenue just a block from the west entrance to the University. About a year later, because of lack of funds, the Desert Laboratory of the Carnegie Institution, located on Tumamoc Hill 3 miles west of the city of Tucson, closed its doors. A plan was developed for several universities, including the University of Arizona, to band together and use the laboratory for a graduate study facility in biological sciences. But, lack of finances prevented this arrangement. Hence, by default, the U.S. Government obtained the laboratory by payment of \$1; the facilities were transferred to the Forest Service, and became the headquarters for the Station.

The laboratory consisted of a main building of native basalt rock construction, 20 by 122 feet. In it was an equipped laboratory with attached greenhouse, an excellent biological library, and five office or workrooms. There was another rock building 28 by 46 feet that was partially burned. These buildings rested on a bench below the top of Tumamoc Hill among the cacti, creosotebush, and other desert plants and animals including

javelina, desert mule deer, and desert foxes. There are several stories concerning the origin of "Tumamoc." One favored is that it is the Papago word meaning "horned toad."

The office for the laboratory was at the bottom of the hill. The only access to the laboratory on the hill was a one-way horse and buggy trail. It was "modernized" for automobile travel by concreting two wheel strips through the rocky section. The water supply was pumped up from the bottom of the hill. The plumbing was modern, but the sewage was piped over the west rock face of the hill.

This was home, and like all homes it was to have and to hold. It took some fixing up! With emergency funds the partially burned building was rebuilt and another rock building about 40 by 40 feet was added. For the next several years "allotment balances" were used to make the facility attractive and comfortable, including the addition of "desert" coolers. Also, a widened automobile access road was added to the Forest Service road system!

During World War II, by agreement, permission was given to Griffith H. Riddle, president of Research Foundation, Inc., a private concern from New York City, to erect some metal buildings on the site for use in conducting radiation studies.

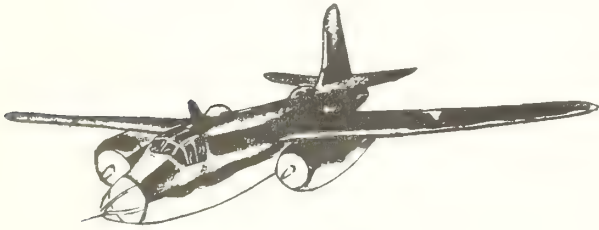
Headquarters, Southwestern Forest and Range Experiment Station, Tumamoc Hill, Tucson, Arizona.



Wartime Casualties

No sooner had the Station become established on Tumamoc Hill than the effects of the war began to be felt and continued well into 1945. The younger scientists entered the military services. Some of the older specialists were assigned to other more direct wartime activities.

Director Upson went to the National War Board to handle national lumber requirements. Cooperrider was sent to search the desert lands in Mexico for rubber-producing plants. McGinnies went to the Emergency Rubber Project in charge of establishing sites for growing and harvesting the guayule plant for rubber production. The few remaining scientists had to do double duty to maintain essential records of continuing research.



Bombs Away!

On top of the wartime casualties at the Station, the civilian real estate arm of the War Department recommended taking over the Santa Rita Experimental Range for a bombing range! U.S. airfields dotted the Southwestern landscape. Practice bombing ranges were needed. Since the Santa Rita was adjacent to three air bases, taking over the Santa Rita seemed a quick and easy way to get a bombing range. After all, it was Government property!

Since the Director and key people at the Station had "gone to war," C. L. Forsling, then Assistant Chief in charge of Forest Research, sent Raymond Price, Assistant Chief, Range Research, to Tucson to save the Santa Rita. Price and K. W. Parker, the remaining principal Range Scientist at the Station, prepared maps, developed their case, and went out to see the Commanding Officer at Davis-Monthan Air Base. The Commander was courteous but a bit fidgety. After listening to their story for about 45 minutes in which Price pointed out the great value and unique features of the Santa Rita—that the values had been built up in the land by reason of its

longtime protection and experimental use, and could never be replaced—the Commanding Officer sat back and said, "A very interesting story, but gentlemen, I have a war to win!" Price quickly replied, "But Colonel, we're making it possible for you to win the next war!" That did the trick, especially with a nudge from his superior officer in San Francisco who was called by phone. The miles of open desert land surrounding the air bases were used for bombing ranges. The Santa Rita was saved and it remains today, the oldest experimental range in existence. And, each year adds more value to this unique area.

In 1942, Price was sent back to Tucson as Acting Director of the Station. The next year he was made Director. Price was a University of Utah graduate. He got deeply involved in athletics at the university so he did not attend a forestry school. In lieu thereof he took forestry-related courses and majored in botany. Later he completed graduate work at Yale University, taking forestry courses and majoring in ecology. He began his career in forestry research at the Intermountain Station in 1931. He was in charge of the Great Basin Branch Station until 1937 when he became Assistant to the Chief, Range Research, Washington, D. C.

Upson and McGinnies did not return to the Station. Upson was appointed in charge of the National Forest and Tropical Station work at Puerto Rico. McGinnies became Director of the Rocky Mountain Station. Cooperrider returned to the Station for a short time, but an infection he acquired while searching for superior guayule plants in Mexico proved fatal. He died at age 55 at the Marine Hospital, Baltimore, Maryland, July 13, 1944. "Coop," as he was known to a host of friends, accomplished much. His greatest achievement was his work in the field of watershed management. A group of Forest Service scientists meeting in a special westernwide range management conference stated "...we missed Coop's friendly smile, able counsel, sage advice, interesting anecdotes, and his technical contributions..."

Accomplishments During War Years

Despite the reduced wartime staff, much was accomplished during the war years. In addition to maintaining essential records for continuing research, some of the accomplishments included the development of the Line Intercept Method of measuring range vegetation by R. H. Canfield; publication of *Southwestern Range Ecology* by McGinnies, Parker, and Glendening; the development of a Range Condition Score Card for judging

rangelands by Parker; and Guides for the Revegetation of Military Areas in Arid Regions by Parker and staff. Some special wartime jobs included test plantings of cork oak by Krauch for possible cork production; measuring temperature and moisture in wooden aircraft wings in cooperation with the Forest Products Laboratory; moisture determination of wooden propellers with the AAF Materiels Command; and participation in agriculture production goals and in postwar planning.

The final year of the war, 1945, was a stress year. Funds and personnel were at a low ebb. But it was also a turning point: later in the year, funds were received to employ the returning veterans. With Cooperrider's death and B. A. Hendrick's retirement, it was necessary to obtain a whole new Watershed Management Research staff. W. P. Martin, a soil specialist, was transferred from the U.S. Soil Salinity Laboratory at Riverside, California, to head up the work. L. C. Rich, hydrologist, transferred from the Soil Conservation Service as Martin's associate. R. K. Hudson, a Junior Forester from Michigan, completed the technical staff.

A bright spot of 1945 was the receipt of new funds to begin formal research in range reseeding. Millions of acres of rangelands were not producing suitable forage, and soil erosion was evident. Range reseeding appeared to be the answer, if suitable species and methods could be developed.

In this research effort, special mention must be made of J. O. Bridges, who began the work in New Mexico. Bridges was experienced in sheep and cattle raising before going to New Mexico A&M College (now New Mexico State University) to teach range management. When the new funds became available for reseeding research, Bridges transferred to the Station to begin the work in New Mexico. He put his gear and grass seeds in his pickup and took off like a "mining prospector" to find out how to reseed the range. He camped out wherever he was when night fell. He was gone before sunup. Hours and accommodations meant little to him. Through his efforts, field nurseries and planting sites were established in the major vegetation types in New Mexico and, contrary to opinions at that time, grass seedings were established! Two years later Bridges went back to cattle raising and cotton growing. H. W. Springfield continued the research in New Mexico. In Arizona, D. M. Thompson, Fred Lavin, G. E. Glendening, and H. G. Reynolds conducted the research.

With Pearson's retirement in 1945, G. S. Meagher returned to the Station in 1946 from the Pacific Northwest Station to head up Timber Management research. It fell Meagher's lot to complete Pearson's ponderosa pine monograph for publication. Meagher could best do it because he assisted in some of the field studies and was well versed in ponderosa pine silviculture.



Director Price, M. W. Talbot, and W. G. Koogler (left to right) examine a rodent enclosure established in 1923 on Tonto National Forest, Arizona. 1946.

High Costs Hamper Research Efforts

Increasing costs of materials and operations reduced the value of the research dollar and made it difficult to do in-depth research. The answer seemed to be to obtain new funds for pressing problems. One of these problems was the wholesale encroachment of shrubby vegetation on rangelands which reduced forage production and contributed to surface soil erosion. Thus it was in 1947 that funds were obtained from the Hope-Flanagan Research and Marketing Act to undertake fundamental research in the physiology and ecology of noxious plants. G. E. Glendening headed the work, and he, H. A. Paulsen, Jr., and S. C. Martin handled the ecological and plant control studies. B. O. Blair started the physiology studies, which centered mainly on mesquite. Later, H. M. Hull and M. E. Roach continued the research until 1954 when they and the research were transferred to the Agricultural Research Service.

In 1948, W. E. Martin left the Station to teach soils at the University of Minnesota where he now heads up the Soils Department. H. C. Fletcher came to the Station from the Soil Conservation Service to replace Martin in charge of Watershed Research. K. W. Parker left the Station for Washington, D. C. to finish developing the Three-Step Method of Range Inventory for National Forest ranges, and later became Chief of the Division of

Range Research. C. K. Pearse, who was Assistant Chief of the Division of Range Research in Washington, D. C., replaced Parker at the Station. Pearse was skilled in range reseeding and range management research, so he kept the work going at a strong pace.

Responding to the developing interest in the Southwest for diversity in forest utilization and lumber production and marketing, Senator Carl Hayden of Arizona in 1950 requested that Congress make funds available to bring the Forest Utilization Service to the Southwest. The request was successful. L. A. Mueller came from the Northern Rocky Mountain Station to head up the work. E. S. Kotok transferred from the Pacific Northwest Station to work with Mueller. They made a good team, and their efforts resulted in much improvement in the forest industry field in the Southwest. Included in their accomplishments were improved milling, seasoning, wood preservation practices, use of paints and finishes, production of veneer and plywood, and improved utilization of wood wastes including the use of woodland and desert shrub species.

The First Research Center

In the interest of curtailing erosion from watershed lands above Elephant Butte Dam, and thereby reducing the silt load in the Rio Grande

Experimental mesquite control by (left) cabling, and (right) spraying. Santa Rita Experimental Range, Arizona, late 1940's.



and prolonging the life of the dam, Congress, in 1951, at the request of Senator Dennis Chavez of New Mexico, appropriated funds to establish a Forest Research Center in northern New Mexico as a part of the Southwestern Station.

With the approval of the University of New Mexico, an amendment was added to the Station's Cooperative Agreement with New Mexico A&M College at Las Cruces (the land grant authority in New Mexico) to locate the Research Center with the University of New Mexico at Albuquerque. This location placed the scientists closer to the problem; also, some library and laboratory facilities were available.

E. J. Dortignac transferred from the Rocky Mountain Station and was placed in charge of the Research Center and undertook watershed research. H. W. Springfield moved from Tucson to Albuquerque to pursue range reseeding research. Grazing trials on watersheds and reseeded areas were undertaken. Those on the lower elevation watersheds outside the National Forests were conducted in cooperation with the Bureau of Land Management, which also helped finance the research. The research results stimulated much reseeding by Federal and State agencies and private individuals. Grazing practices were also improved, resulting in better range conditions.

This same year (1951) Meagher returned to the Pacific Northwest Station in charge of Timber Management Research. E. M. Gaines transferred from the Southern Station to replace Meagher. Gaines also became leader of the Flagstaff Research Center, which included Range Research on forested ranges conducted by J. F. Arnold. Other Research Centers established were the Jornada at Las Cruces, New Mexico, with H. A. Paulsen, Jr. in charge, and the Santa Rita at Tucson, Arizona, with G. E. Glendening in charge.

The Beginning of the Arizona Watershed Program

The informal relationship with the Salt River Water Users Association at Phoenix, Arizona, was formalized during 1953. The Association entered into a Cooperative Agreement with the Station concerning the harvesting of timber on the Workman Creek watershed at the Sierra Ancha Experimental Forest. The objective of the research was to determine the effects of different levels of timber removal on water yield and soil erosion. The research was planned to continue until 1980. The project marked the beginning of the unique Arizona Watershed Program, which will be discussed later.

SOUTHWESTERN FOREST AND RANGE EXPERIMENT STATION

Tumamoc Hill, Tucson, Arizona

Program Conference—1951

(Left to right)

First row: F. N. Ares, R. H. Canfield, N. Cobb, Geraldine Peterson, Dorothy Smith, Helen Hunt, Alice Martin, Georgia Savage, Florence Martin, E. C. Martin, E. J. Dortignac, L. R. Rich.

Second row: D. N. Anderson (SCS), G. E. Glendening, H. W. Springfield, Director Price, Pablo Lucero, J. W. Bohning, J. F. Arnold, C. K. Pearse, L. A. Mueller.

Third row: E. M. Gaines, K. W. Parker, F. R. Herman, H. A. Paulsen, Jr., H. G. Reynolds, F. R. Lavin, E. S. Kotok, H. C. Fletcher.



The Rocky Mountain Forest and Range Experiment Station, 1935-53

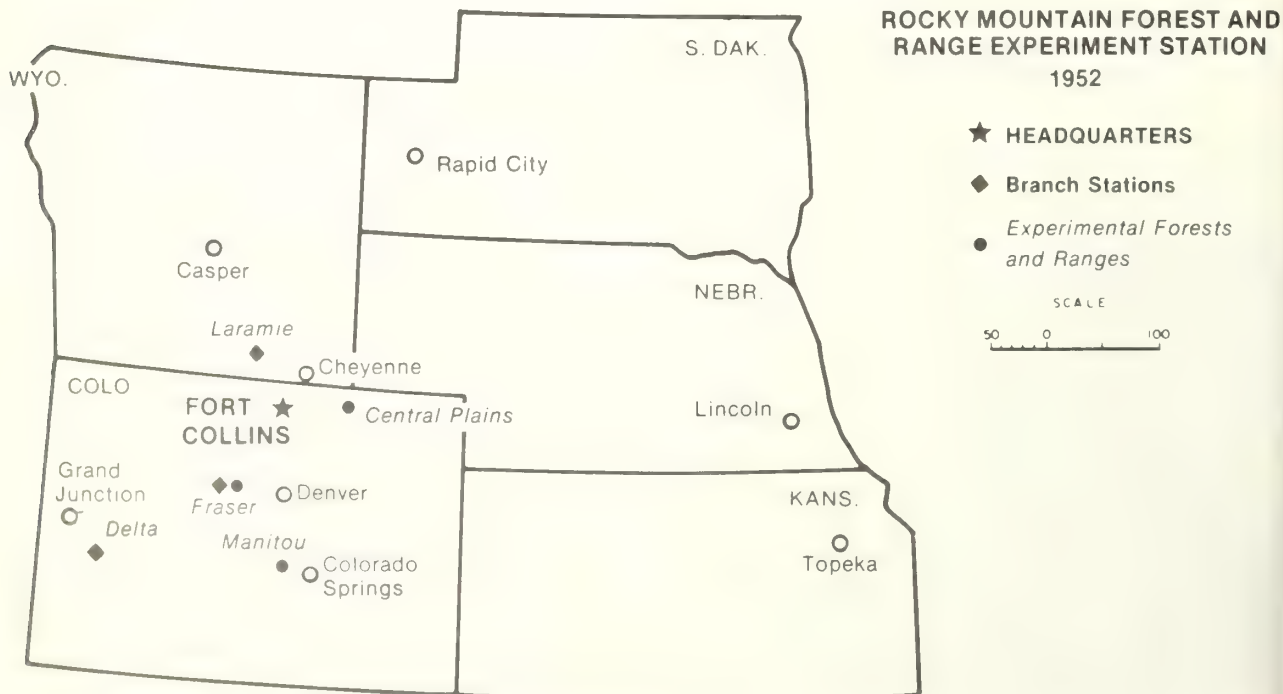


The Rocky Mountain Forest and Range Experiment Station, the last of the 12 regional forest experiment stations funded under the McSweeney-McNary Act of 1928, was established July 1, 1935.

The Rocky Mountain Station area included the States of Colorado, Wyoming (east of the Continental Divide), western South Dakota, Nebraska, and Kansas. Under cooperative agreement, the Station was headquartered with Colorado College of Agriculture and Mechanic Arts

Headquarters, Rocky Mountain Forest and Range Experiment Station, second floor of forestry building, built in 1937 on Colorado A & M campus.

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*Directors,
Rocky Mountain Forest and Range
Experiment Station, 1935-53:*

Richard E. McArdle, 1935-38



Charles A. Connaughton, 1938-44



William G. McGinnies, 1944-53



(now Colorado State University) at Fort Collins. For the first year, offices were on the top floor of the Administration building. During the following year the Station moved to the new Forestry building constructed by the College.

All research work previously handled by the Forest Service in the central Rocky Mountain region, including the 500-acre Fremont station at Manitou, was absorbed by the new regional Rocky Mountain Station.

R. E. McArdle, who later became Chief of the Forest Service, was the first Director of the Station. McArdle earned his B.S., M.S. and Ph.D. degrees from the University of Michigan. He was Dean of the School of Forestry at the University of Idaho at the time of his selection. Prior to this, McArdle was engaged in forest research at the Pacific Northwest Station. McArdle's choice as Director was a good one. With his unusual ability to meet and work with people, he quickly established the Station as a productive cooperative unit.

"Hat in the Ring"

The story is told that early in the history of the Station McArdle was at the Regional Forester's office in Denver. The Regional Forester was meeting with some of his top staff. Little attention was being paid to McArdle—he was not being included in the discussion. So, in his characteristic unusual manner, McArdle stepped back and threw his hat into the center of the room and said, "Gentlemen, there is another hat in the ring now!" That broke the ice. Regional Forester Peck traveled with McArdle around the Region during the next several months. This established Research as an integral part of the Forest Service in Region 2.



Another incident characteristic of McArdle happened when he was in Washington helping to write the Range Report.¹⁷ Earl H. Clapp, Asso-

ciate Chief, was "cracking the whip" on the report. Clapp announced that nobody could leave until the report was finished—at least one would have to have an excuse that he had not heard before he would consider their leaving. Meantime, the new Forestry building at Fort Collins was nearing completion. Interestingly, McArdle received a wire from the President of Colorado A&M College asking him to be present for the cornerstone laying! McArdle took the wire in to Clapp. After reading the wire, Clapp threw up his hands and with a chuckle said, "Mac, you've done it again; go on home!"

Initial Organization

By April of 1936 a staff was assembled and on the job at the new Station. The initial appropriation was \$75,000. This was broken down to \$25,000 each for Timber Management, Range Management, and Watershed Management Research.

Organization of the Rocky Mountain Forest and Range Experiment Station, 1935¹⁸

Director: R. E. McArdle

Timber Management:

R. F. Taylor, in charge

Mensuration—E. W. Hornibrook

Regeneration—Jacob Roeser, Jr.

Range Management:

L. J. Palmer, in charge

Range Forage—D. F. Costello

Range Management—L. J. Palmer

Watershed Management:

C. A. Connaughton, in charge

Erosion—C. A. Connaughton

Watersheds—W. M. Johnson

Experimental Forests and Ranges:

Fremont—Colorado Springs, Colo.

R. F. Taylor came to the Station from the Washington, D. C. office. E. W. Hornibrook transferred from the Southwestern Station. J. Roeser was already on the job at Fremont. L. J. Palmer transferred from the Fish and Wildlife Service, Department of the Interior. He was working in Alaska on reindeer range work. C. A. Connaughton, D. F. Costello, and W. M. Johnson all transferred from the Intermountain Station.

¹⁷U.S. Department of Agriculture. Forest Service. 1936. The western range. U.S. Sen. Doc. 199, 74th Congr., 2d Sess., 620 p. Gov. Print. Off., Wash., D.C.

¹⁸U.S. Department of Agriculture. Forest Service. 1936. Report for 1935 and research program for 1936, Rocky Mountain Forest and Range Experiment Station. 11 p. Fort Collins, Colo.

Regional Research Councils and Program Formulation

To assure that research at the Station did not duplicate the work by other research agencies, that these other agencies would know the work of the Station, and that the Station would be kept informed of problems and current developments, a Regional Research Council, as used by other Stations, was formed. Membership was drawn from other research agencies, industry representatives, and Federal and State forest and range land-management agencies. At first the Council was organized into three committees, one for each of the major fields of research, with plans for regular meetings. In later years, the Council became more informal and met as the occasion demanded.

As a result of the committee meetings, a research program in each of the three fields of research was formulated. Attention was given to (1) the most important problems, (2) solutions that would be beneficial to the land users, (3) the necessity of concentrating longtime research on experimental forests and ranges, and (4) acquainting members of the Station with the region as quickly as possible.¹⁸

The initial studies in **Timber Management Research** were growth and yield studies, volume

Pike National Forest, Colorado, April 1939:

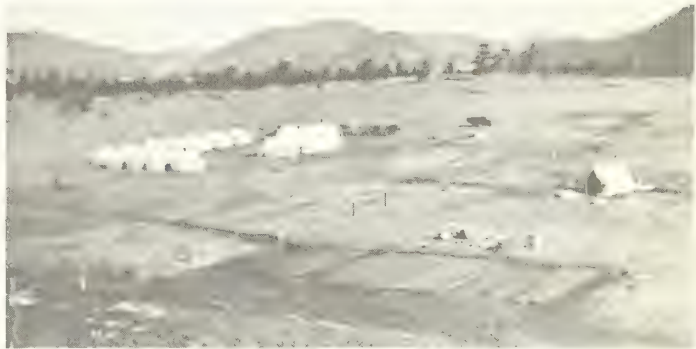
(Left) R. Stahelin, weighing snow.

Ponderosa pine grading experiment:

(Upper right) Planting camp, with heeling-in beds in foreground; planting furrows behind tents; and packing tent at right. (Center) Planting trees. Stakes of a watershed experiment plot in background. (Lower right) Faller uses old inner tube fastened to stake to help pull saw back through cut. Black Hills, South Dakota.

studies, regeneration studies, and silvicultural studies. Those in **Range Management** included a host of management problems requiring many years to solve. However, immediate attention was devoted to a survey of range forage conditions, and plant development in relation to grazing periods. In **Watershed Management Research**, a host of water problems were also recognized to be solved over the years. But, again first effort was centered on a survey of the extent and character of soil erosion on the National Forests, the influence of vegetative cover on runoff and erosion, and use of water by vegetation.

During the next 2 years, 1936 and 1937, work progressed rapidly. Growth and yield tables for ponderosa pine in the Black Hills were completed; preliminary data were gathered for lodgepole pine. The survey of erosion on National Forests was completed. Effort on the Western Range Survey was completed and Flood Control Surveys began.





*Headquarters, Manitou Experimental Forest, Colorado, 1940.
(Left) Office (Right) Lodge.*

Manitou Experimental Forest

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The Manitou Experimental Forest,¹⁹ established in 1936 near Woodland Park, lies 28 miles northwest of Colorado Springs, and covers 25 square miles in the ponderosa pine lands of the Colorado Front Range. Colorado College at Colorado Springs cooperated for a short time in the early research work. The initial cooperation with a Federal agency was with the Farm Security Administration, U.S. Department of Agriculture, who had built the attractive stone buildings that became the Manitou headquarters. Just before the Station was to take over the property, the large stone building (lodge) completely burned. The agency, and a work camp of the Works Progress Administration (WPA), rebuilt the building.

The Experimental Forest was established primarily for watershed management research purposes—to determine principles and methods of management of the critical ponderosa pine Front Range area for watershed protection and to curtail floods and erosion. Some of the lower open lands had been farmed; also, much of the area was being grazed by cattle. Hence, intensive tests of species and methods of reseeding were conducted as a range rehabilitation measure. Also,

pasture tests of the intensity, seasons, and systems of cattle grazing were conducted to develop guides for range cattle management for the ponderosa pine Front Range area. The results obtained have been of far-reaching benefit. Many stockmen, water users, range extension specialists, scientists, students, and general public have visited and studied the results of the research. W. M. Johnson played a major role in the development and conduct of the work at Manitou. L. D. Love directed some of the early work and participated in the watershed studies. P. O. Currie has been in charge in later years.

¹⁹Love, L. D. 1958. *The Manitou Experimental Forest—its work and aims*. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 7, 21 p. (Rev.). Fort Collins, Colo.



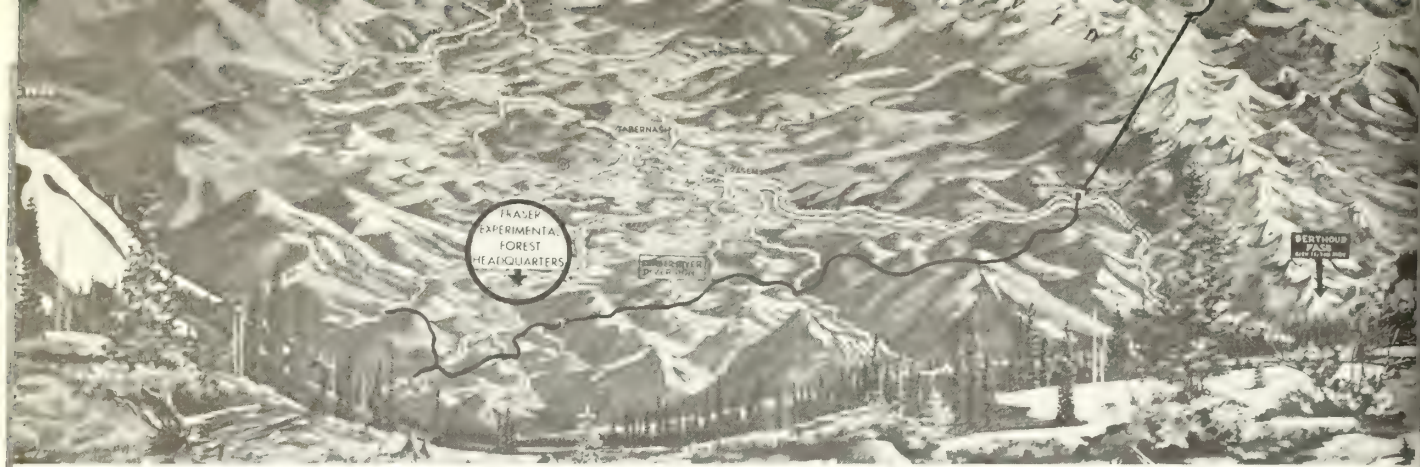


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Manitou Experimental Forest, Colorado:

- ◆ ***(Left) Grazing on intermediate wheatgrass planted on abandoned field, 1951.***
- (Top) Measuring density of protected plants on cattle range, 1941.***
- (Center) Abandoned field reclaimed through re-seeding, 1944.***
- (Right) Grass nursery adaptability trials, 1950.***





Fraser Experimental Forest

The Fraser Experimental Forest was established in 1937.²⁰ It is situated in the heart of the Central Rocky Mountains near the Continental Divide 65 miles north and west of Denver near Fraser, Colorado. The dominant tree species are lodgepole pine, Engelmann spruce, and subalpine fir. Aspen grows in the openings left by fire and logging. Higher in the alpine areas are barren rocks intermixed with meadows containing grasses, sedges, forbs, and dwarf willows. This 36-square-mile outdoor research laboratory was selected to study pressing problems related to water yield from high-elevation forests and alpine areas. Water from much of the area is diverted to the City of Denver, and a prime purpose of the Experimental Forest was to find out how to get more water from snowmelt.

Various methods and arrangements of timber harvests were made, and the snow storages measured and translated to water yield; also measured were the growth and mortality of the tree species. Streamflow and siltation from the harvested watershed were compared to that from the unharvested check watershed. The results have been of great importance to water users and forest land managers nationwide. The timber on the original harvest cutting plots was cut and skidded by Public Works crews. The timber harvest was directed by the Arapaho National Forest.

Many people, including foreign delegations, have visited the Experimental Forest. It has also been used for training schools and field meetings by various institutions and associations. Many scientists and students have worked at Fraser. Those who were chiefly responsible included C. A. Connaughton, H. G. Wilm, B. R. Lexen, B. C. Goodell, R. R. Alexander, and M. D. Hoover.

²⁰Love, L. D. 1960. *The Fraser Experimental Forest—its work and aims*. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 8, 16 p. (Rev.). Fort Collins, Colo.



Headquarters, Fraser Experimental Forest, Colorado. Lodge and mess hall.

R. A. Read (standing) and E. G. Dunford, weighing and recording a snow core on a commercially clear-cut plot. Fraser Experimental Forest, Colorado, 1941.





Headquarters, Central Plains Experimental Range, Colorado. G. E. Klipple records the vegetation density in an experimental pasture, 1942.



Central Plains Experimental Range

The development of the Central Plains Experimental Range was begun in 1939 in cooperation with the U.S. Soil Conservation Service. Located 12 miles northeast of Nunn, Colorado, and 25 miles southeast of Cheyenne, Wyoming, the 12,800-acre experimental range is in the western part of the Central Great Plains region. Blue grama and buffalograss are the dominant forage grasses.²¹ To furnish guides to proper management of the extensive range type, yearling heifers were grazed in pastures under three grazing intensities to determine the effects on the range and on the cattle. The Experimental Range was transferred to the Agriculture Research Service in 1954 in the reorganization of the Department of Agriculture. D. F. Costello and G. E. Klipple developed the Experimental Range, and gave direction to the research.

²¹Klipple, G. E., and David F. Costello. 1960. *Vegetation and cattle responses to different intensities of grazing on short-grass ranges on the central Great Plains*. U.S. Dep. Agric., Tech. Bull. 1216, 82 p.



David F. Costello (upper) weighs cattle used in experimental grazing systems, and (lower) reports a light-use pasture in high-fair condition. 1942.



Key Personnel Changes

The years 1938 and 1939 were marked by changes in key personnel. C. A. Connaughton took over the Directorship of the Station in 1938. McArdle went to Asheville, North Carolina, as Director of the Appalachian Station. H. G. Wilm, from the California Station, replaced Connaughton as Chief of Watershed Management Research. L. J. Palmer returned to Alaska. D. F. Costello became Chief, Range Management Research, and J. T. Cassady joined the range staff. Rudolph Stahelin was added to the Timber Management Research staff.

In 1939, B. R. Lexen transferred from the Southwestern Station, and replaced Taylor as Chief of Timber Management Research. G. T. Turner and Clyde Doran joined the Range staff, and M. H. Collet and C. H. Niederhof were added to the Watershed Management staff. Wilm was also in charge of Flood Control Surveys with L. K. Hill, W. M. Johnson, H. D. Burke, and E. G. Dunford.

Connaughton, a University of Idaho forester, completed his M.F. at Yale. He was an organization and action man. Things moved under his

friendly but objective leadership. Under his direction, an in-depth analysis was made of the wildland management problems of the Region. In **Timber Management**, the problems were segregated by major forest types; that is, Engelmann spruce, lodgepole pine, ponderosa pine, and other minor forest types, chief of which was Douglas-fir. In **Range Management**, problems were arranged in three broad categories or areas, each characterized by certain vegetative types, climate, physiography, and economics. They were the Great Plains, the sagebrush-grass and semidesert areas, and the mountain area. In **Watershed Management**, the problems were arranged into four broad areas or zones, namely the Great Plains, the Foothills, the Front Range, and the Main Rocky Mountain Range.

Much useful information was made available: reforestation procedures, tree classification of lodgepole pine, growth and yield of selectively cut lodgepole pine, growth after thinning in ponderosa pine; also, the influence of vegetation on surface runoff and erosion, the most desirable reforestation sites, and information on snow storage and rate of melting. Other accomplishments included reports on initial stocking rates



ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fort Collins, Colorado

Staff—1943

(Left to right)

First row: D. F. Costello, P. L. Ginter, H. G. Wilm, Maria Garwood, N. D. Wygant (Cooperator, Division of Forest Insect Investigations, BE&PQ), E. G. Dunford, B. R. Lexen.

Second row: Director C. A. Connaughton, C. W. Maxey, E. M. Hornibrook, W. M. Johnson, G. E. Klipple.



Grazing experiments with heavy, moderate, and light grazing on experimental pastures at Manitou Experimental Forest, Colorado, 1940's.

for cattle for the Manitou pastures; effect of grazing by cattle on the Central Plains Experimental Range; research in the control of orange sneezeweed (*Helenium hoopesii*); and a study course in Range Ecology. A milestone was the marking of lodgepole pine for various degrees of harvesting in the timber-water yield study at the Fraser Experimental Forest.

In 1940, the forest and range problems of the Region were reappraised. Several important problems were recognized in each of the broad areas or zones: the Great Plains, the Foothills, the Front Range, the Main Rocky Mountain Range, and the Colorado Plateau. However, within the funds and facilities available, research was directed chiefly on a few critical areas including: **Range Management**, ponderosa pine and short-grass ranges and poisonous plant control, principally orange sneezeweed; **Timber Management**, management of the Engelmann spruce type and artificial regeneration; **Watershed Management**, Front Range and the Main Range. W. M. Johnson was given charge of the Manitou Experimental Forest.

G. T. Turner evaluates the mima mounds attributable to pocket gophers on Black Mesa, Colorado, 1947.



Streamlined Program During War Years

During the war years, 1941 to 1945, the main emphasis of the Station program shifted to problems directly associated with World War II and immediate postwar effort. Less urgent work was placed on a maintenance basis, because funds and personnel were reduced to a minimum. The younger scientists entered the military services. Those remaining continued the essentials of the more important established research, and also handled special related wartime activities. Some of these included a study of supply and requirements of forest products for the Rocky Mountain region, the development of shortcut labor-saving methods of handling timber sales, U.S. Department of Agriculture War Board assignments, Food for Freedom Program, a study of native rubber-bearing plants, and plant collections for special wartime insecticide programs. B. R. Lexen was transferred to the Guayule project for research and survey purposes. P. L. Ginter joined the Station and, in cooperation with Region 2, handled the Timber Products War Projects.

Despite the wartime restrictions, the Engelmann spruce area at Fraser was prepared for the key experimental water-timber cuttings. In Range Management Research, a study of the effects of pocket gophers on range condition and grazing capacity on summer ranges of the Plateau area on the Grand Mesa National Forest were begun; also, the ponderosa pine range-watershed study was started at Manitou. Three degrees of grazing were imposed on the pastures.

In 1944, Connaughton transferred to the Directorship of the Southern Forest Experiment Station. W. G. McGinnies of the Emergency Rubber Project was appointed Director. McGinnies was a 1922 University of Arizona graduate with a B.S.A. in biology; he obtained his Ph.D. in ecology (1932) at the University of Chicago. Subsequently, he was Range Ecologist and Professor of Botany at the University of Arizona (1927-35) and then with the U.S. Soil Conservation Service, before joining the Southwestern Station.

Post-War Rebuilding Program

In mid-1945 as the war ended, some new funds became available to revitalize the research program. Formal research in range reseeding was begun by C. L. Terrell. B. C. Goodell joined the Watershed Management staff. J. L. Retzer, Soil Scientist, also joined the staff. Retzer's soil skills added another dimension to the Station's program. His first effort, working with Region 2, was evaluating soils in range surveys and special soils investigations. Retzer classified wildland soils of the Region preparatory to the conduct of intensive forest and range research. Later, Retzer transferred to Washington, D. C., to organize and head up nationwide soil surveys on the National Forests.

Reorganization of Research Into Research Centers

Funds were made available in July 1946 for conducting forest and range research in western Colorado. In accordance with "Hearings on the U.S. Department of Agriculture Appropriation Bill for 1947," this new research was established and organized as the Western Slope Research Center. Following this same pattern, the research at the Station was also organized into the Front Range and Continental Divide Research Centers. These Research Centers operated as Branch Stations under the general supervision of the central staff.

The Central Plains Experimental Range was administered by the Division of Range Management Research with G. E. Klipple as Superintendent. The Fraser Experimental Forest was the principal work center for the Continental Divide Research Center; B. R. Lexen was acting Research Center Leader, with E. M. Hornibrook and B. C. Goodell. Front Range Research Center work was concentrated at the Manitou Experimental Forest; W. M. Johnson was Research Center Leader with

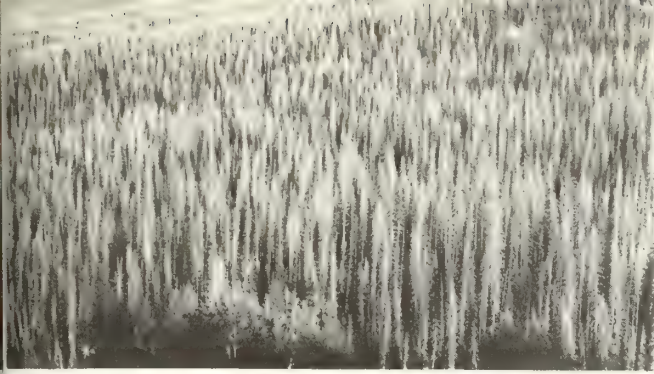
E. J. Dortignac and C. L. Terrell. G. T. Turner was Acting Research Center Leader of the Western Slope Research Center, with C. W. Doran. Leaders for all three Research Centers maintained headquarters at Fort Collins. The central staff at Fort Collins included B. R. Lexen, in charge Timber Management Research; H. G. Wilm, in charge Watershed Management Research; D. F. Costello, in charge Range Management Research, and J. L. Retzer, Special Soils Investigations.

In 1947, the personnel assigned to the Western Slope Research Center moved to Delta, Colorado. They operated out of the Supervisor's Office of the Uncompahgre National Forest. Stream-gaging stations were established on three timbered watersheds of Red Sandstone Creek, White River National Forest. The Research Center moved to Grand Junction in 1955; in 1960, the personnel moved back to Fort Collins.

Sneezeweed control, range reseeding, and cooperative pocket gopher research were included in the program of the Western Slope Research Center. E. J. Dortignac was transferred from the Front Range Research Center to the Western Slope staff. Other personnel changes included the addition of E. G. Dunford, Soil Scientist, to the Front Range staff. C. L. Terrell joined the Colorado State Cooperative Extension Service as Extension Conservationist. Later he handled State and Extension Forestry, and in 1959 was appointed Secretary to the State Board of Agriculture. W. M. Johnson and E. G. Dunford moved to the Manitou Experimental Forest residences.

In 1948, special attention was given by the Timber Management staff to reproduction and stand condition in the beetle-killed spruce stands of the Colorado Plateau area. Range reseeding tests and research in sagebrush control were begun in Wyoming in cooperation with the Bureau of Land Management and Wyoming Agricultural Experiment Station. Attention was centered on adaptable species and seedbed preparation. L. D. Love transferred to the Station from the U.S. Soil Conservation Service to replace Wilm as head of Watershed Management Research. Wilm transferred to the Southern Station. A. C. Hull transferred to the Range Management staff from the Intermountain Station, to conduct range reseeding research.

In 1949, the research program at the Station was reviewed in relation to watershed management and river basin planning and development, which was then receiving nationwide attention. This was apropos, as the central Rocky Mountain Region is the fountainhead of four major rivers. In cooperation with D. V. Harris of the

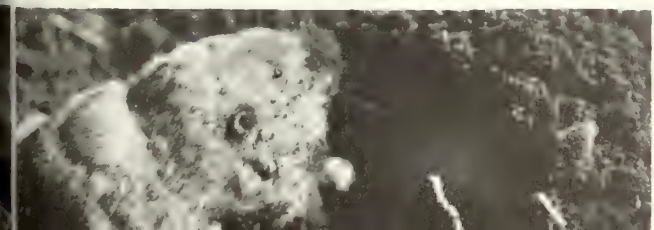


Devastation of Engelmann spruce by the spruce beetle, 1939 to 1953, did much to get insect control research rolling. On the White River National Forest, Colorado, beetles destroyed entire stands—3.8 billion board feet of Engelmann spruce and 500 million board feet of lodgepole pine.



Both airplane and tractor-mounted spraying equipment were used for sagebrush-control experiments in Wyoming in the 1940's.

Building a gopher exclosure study area on Black Mesa in western Colorado.



East St. Louis watershed, Fraser Experimental Forest, Colorado, 1950, where relation of streamflow to extent of snow cover was recorded. Before April 1, entire watershed was snow covered; most snow had disappeared by July 3.

Upper, June 2;

Center, June 19;

Lower, July 3.



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Geology Department of Colorado A&M College (later named Colorado State University), studies were begun to evaluate the geologic factors in erosion. Also in 1949, a group of Forest Service watershed and timber management scientists from various parts of the United States met at the Fraser Experimental Forest to consider experimental evidence and plans for the classic Fool Creek timber-watershed study. This "Fool Creek Jury" agreed that the area was ready for experimental treatment as follows:

1. Construct logging roads prior to harvesting and evaluate effects on streamflow.
2. Remove some 3 million board feet of timber by alternate-strip cutting, and evaluate effects on streamflow.
3. About 1960 remove remaining timber, and evaluate effects on streamflow.



FOOL CREEK JURY, FRASER EXPERIMENTAL FOREST, 1949.

(Left to right)

Front row: M. B. Huckleby, M. D. Hoover, L. Lassen, T. Krueger.

Second row: Director W. G. McGinnies, R. K. LeBarron, R. W. Bailey, J. J. Byrne.

Third row: B. C. Goodell, E. N. Munns, E. J. Dortignac, E. G. Dunford, P. A. Ingebo, B. R. Lexen.

Fourth row: L. D. Love, J. G. Osborne, A. R. Croft, A. G. Lindh, C. M. Hendee, J. L. Retzer.



Timber harvest patterns designed for evaluating effects of water yield and forest regeneration. Fool Creek watershed, Fraser Experimental Forest, Colorado. Access roads were built in 1950-51; timber harvesting was done in 1954-56.

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A sediment basin of $\frac{1}{4}$ acre-foot capacity was constructed in 1951 immediately below the stream-gaging station. Annual sediment yield from the watershed following logging averaged only 1.5 cubic feet per acre, net volume.



Other Programs in the Early Fifties

Despite the decreasing purchasing power of the dollar, other progress was achieved during the early fifties. In 1951, the Fool Creek program began. Previous work with small sample plots at the Fraser Experimental Forest furnished background information and suggested possible treatments. Work in Wyoming in cooperation with the University of Wyoming was extended to the Bighorn area, where intensity-of-grazing studies were begun. Plans for an Experimental Range on Black Mesa, Gunnison National Forest, Colorado, were developed and cooperative grazing studies with the Black Mesa Cattlemen's Association were begun in 1952. Intensity of grazing was put to the test at Manitou in the drought years then existing, and recommendations made available.

The National Forest Advisory Council raised questions about livestock grazing on important watersheds of the Front Range of Colorado. To answer these questions, in 1950, E. H. Reid, Division of Range Research, Washington, D. C. Office, headed up a team of resource scientists and made a study of the Elk Ridge and Lower Elk Ridge cattle allotments on the Roosevelt National Forest, Colorado.²² Recommendations from the

Roosevelt study emphasized the need to consider all resource values such as soil productivity, erosion, streamflow, wildlife habitat, timber production, and recreation aspects along with range condition and trend, in establishing range livestock grazing policies for National Forest ranges.

The following personnel changes occurred in 1951: (1) J. H. Buell replaced Lexen in charge of Timber Management Research. Lexen was transferred to Washington, D. C., in Timber Management Research. Later he transferred to the Department of Agriculture in charge of foreign forestry, P.L. 480. Buell transferred from the Washington Office of Timber Management Research. (2) E. G. Dunford was made Research Center Leader of the Continental Divide Research Center. (3) A. C. Hull, Jr. was transferred to the Washington office in Range Research. (4) R. M. Hurd came from the Washington office to be Research Center Leader of the Big Horn Research Center. He was assisted by N. A. Kissinger. (5) R. R. Alexander joined the Timber Management staff, and H. E. Brown the Watershed Management staff.

In 1952 arrangements were made for beginning the appraisals of shelterbelts in Nebraska, Kansas, and South Dakota. Cooperation was worked out with the Nebraska Agricultural Experiment Station for the assignment of R. A. Read at Lincoln, Nebraska, to begin the work. During the year, Dortignac was transferred to the Southwestern Station to head up the work in northern New Mexico. H. E. Brown was transferred to the Western Slope Research Center to replace Dortignac.

²²Reid, Elbert H., and L. D. Love. 1951. *Range-watershed conditions and recommendations for management, Elk Ridge and Lower Elk Ridge cattle allotments, Roosevelt National Forest, Colorado*. 123 p. U.S. Dep. Agric., For. Serv., Wash., D.C.

This shelterbelt, planted in 1938 (upper), was evaluated in 1954 (lower).





A sign "Ike Ate Here" hangs over the entrance to the dining room of the "lodge" at the Fraser Experimental Forest. President Dwight D. Eisenhower was a guest at the Byers Peak Ranch at Fraser, Colorado, for part of the summers of 1953, 1954, and 1955. The Experimental Forest joins the west boundary of the Ranch.

During the summer of 1953, arrangements were made with Sherman Adams, Special Assistant to President Eisenhower (formerly a lumberman), for the President to visit and have lunch at the Experimental Forest. As the President entered the cook house, he smelled the soup being prepared by Andrew J. O'Mailia, the summer cook at the Experimental Forest. The President tasted the soup, and this started a friendly conversation between him and "Andy" about recipes. Occasionally "Andy" took a pie to the Ranch for the President. During a visit to the Ranch in the summer of 1954, "Andy" mentioned to the President that he read where he—the President—was

going to Missoula, Montana, to dedicate a new Forest Service smoke-jumpers headquarters. "Andy" asked the President to say hello to his boss Richard E. McArdle, Chief of the Forest Service. Following is a quote from the President's remarks at the ceremony:

I am not at all surprised that it [the Forest Service] is such a good outfit . . . two nights ago in Fraser, Colorado, I was visited by a cook, a cook in the Forest Service. He said, "I read in the paper you are going to Missoula. There you will see my boss, Mr. McArdle. Give him my greetings and best wishes."

I was long with the Army, I have seen some of the finest battle units that have ever been produced, and whenever you find one where the cook and the private in the ranks want to be remembered to the General, when someone sees him, then you know it is a good outfit.

"Andy" and his cooking did much to facilitate the research at the Fraser Experimental Forest.



**ROCKY MOUNTAIN FOREST AND RANGE
EXPERIMENT STATION
Fort Collins, Colorado
Staff—1951**

(Left to right)

First row: Director W. G. McGinnies, R. R. Alexander, D. F. Costello, E. G. Dunford, L. D. Love, C. M. Doran, J. L. Retzer.

Second row: Joye E. Smith, Maria D. Garwood, Mona F. Nickerson, Marie H. Gurwell, Annalea C. Busch.

Third row: G. T. Turner, C. L. Newman, G. E. Klipple, W. M. Johnson, R. D. Hurd, N. A. Kissinger, J. H. Buell.

Consolidation of Rocky Mountain and Southwestern Stations, 1953

The steady decline in quantity and value of the research dollar in the early fifties was causing a gradually declining research program at the several regional forest experiment stations, especially at the smaller western stations. This situation made it difficult to operate, and to entice and hold good scientists.

The Forest Service, constantly studying ways and means to meet changing needs and problems, and after a thorough 2-year study, deemed it advisable to consolidate the smaller western stations. Hence, in 1952 the Northern Rocky Mountain (Missoula, Montana) and the Intermountain Stations were consolidated as a new Intermountain Station with headquarters at Ogden, Utah. A year later, September 1953, the Rocky Mountain and Southwestern Stations were consolidated as a new Rocky Mountain Station with headquarters in Fort Collins, Colorado, in cooperation with Colorado A&M College (later called Colorado State University). Fort Collins was a more central location with available library and research facilities. Improved transportation helped make the consolidations possible.

Several advantages resulted from consolidating the two stations. The elimination of one Director's office made funds available to continue and generally strengthen going research, and made possible an enlarged, more comprehensive, and more closely correlated program. Formerly, only partial programs in a few fields were possible at the two stations. After consolidation, more skills and services became available to the people and interests in the central and southern Rocky Mountain Regions. Consolidation, of course, has its limits, but in this case it proved beneficial. The area served has many problems in common, so that basic facts obtained have wide application.

Organizations Meshed and Decentralized

Raymond Price moved to Fort Collins as Director of the combined Stations. McGinnies moved to Columbus, Ohio, as Director of the Central States Station. Other personnel of the two Stations were meshed together into a productive organization.

In the Director's office, J. H. Buell continued as Division Chief of Timber Management Research. M. D. Hoover transferred from the Southeastern Station to head up Watershed Management Research; and E. H. Reid came from the Washington office to head up Range Management Research. Previously, C. K. Pearse had taken a foreign assignment, and D. F. Costello had transferred to the Pacific Northwest Station. L. D. Love became Leader of the Front Range Research Center, and H. C. Fletcher became Leader of the Sierra Ancha Research Center. Hoover and Reid, with their rich experience in Watershed Management and Range Research, gave impetus to the station program and helped develop the younger scientists in these fields. L. A. Mueller and E. S. Kotok moved from Tucson to Fort Collins to work Stationwide in forest utilization.

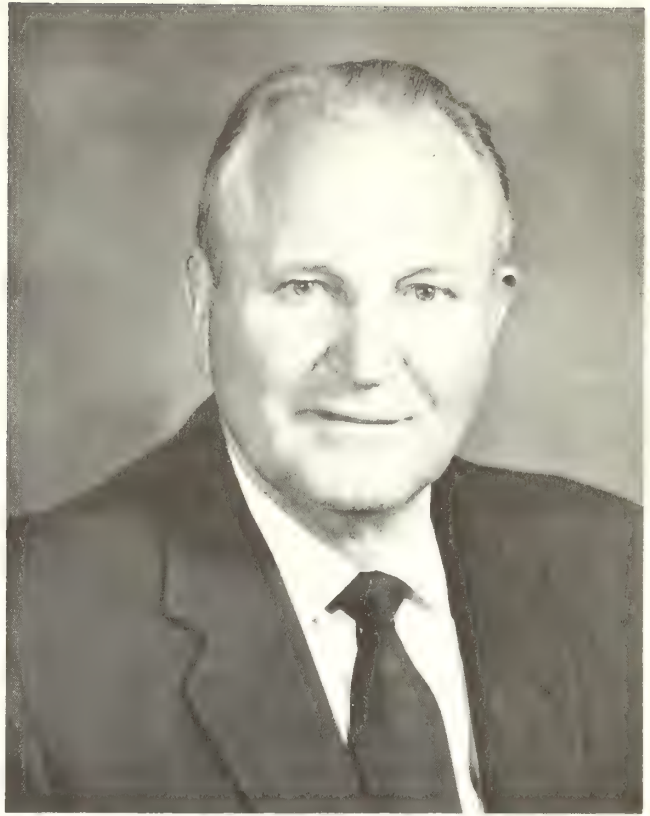
To effectively administer the broader and more comprehensive program of the new Station within the enlarged area to be served, the research was organized and conducted on a research center basis. This organization was not new. It had been followed by the Forest Service in the East and South for several years and on a partial basis by the former two Stations. Now, except for special services, the entire Station program was so organized and managed.

Most of the technical personnel were located at nine research centers. These included the Santa Rita, Sierra Ancha, and Fort Valley Research Centers in Arizona; the Upper Rio Grande in New Mexico; the Upper Colorado (Western Slope), Continental Divide, and Front Range in Colorado; the Big Horn in Wyoming; and the Prairie Research Project in Nebraska. Other research areas were recognized, such as the Black Hills of



***Directors,
Combined Rocky Mountain Forest and
Range Experiment Station, 1953-75:***

Raymond Price, 1953-71



Karl F. Wenger, 1971-75



David E. Herrick, 1975-present



South Dakota and Wyoming, and the Trans Pecos in west Texas and New Mexico. These areas were not then activated, however, since appropriated funds were lacking.

The Research Center organization proved to be effective for the times and had several marked advantages: (1) because scientists resided within the areas, they became more intimately acquainted with the people and the problems needing attention; and (2) the people within the areas had a greater opportunity to take part in the programs. As a result, the research was more directly oriented to local problems, and the findings more easily put into practice.

Department of Agriculture Reorganization

Secretary Benson's memorandum of November 2, 1953, pertaining to the reorganization of the Department of Agriculture, transferred Forest Insect Investigations, of the Bureau of Entomology and Plant Quarantine, and Forest Pathology, of the Bureau of Plant Industry, Soils, and Agricultural Engineering, to the Forest Service and added them to the programs of the forest and range experiment stations. Hence, the Forest Insect Investigation Unit at Fort Collins, headed by N. D. Wygant, and the Forest Pathology Unit at Albuquerque, New Mexico, headed by L. S.

Gill, were added to the newly formed Rocky Mountain Station. Wygant became Chief of Forest Insect Research at the Station, and L. S. Gill came to Fort Collins as Chief of Forest Disease Research. The other personnel of these units were organized into two Forest Insect and Disease Laboratories. One was headquartered in Albuquerque, New Mexico, to serve the States of Arizona and New Mexico, and the other at Fort Collins to serve the remainder of the Station area.

As a part of the reorganization of the Department of Agriculture, certain phases of range research of the Forest Service were transferred to the Agricultural Research Service. All range research in the Great Plains, including the Central Plains Experimental Range and the Jornada Experimental Range, were transferred to the Agricultural Research Service. Also transferred from the Forest Service to Agricultural Research Service was research in range reseeding, except for reseeding for wildlife and management of reseeded ranges. Research projects on methods to control undesirable range plants were also transferred, except for control by grazing management or fire and ecology studies. The scientists transferred to the Agricultural Research Service remained in place at the Station's Research Centers for several years and worked on a cooperative basis. These included G. E. Klipple at Fort Collins, F. Lavin at Tempe, H. M. Hull and M. E. Roach at Tucson, and F. N. Ares at Las Cruces.

N. D. Wygant (left) checks an insect attack near Cameron Pass, Colorado. L. S. Gill watches as S. R. Andrews transfers fungus cultures at the Forest Diseases Laboratory, Albuquerque, New Mexico.



**Organization of the Rocky Mountain
Forest and Range Experiment Station,
after Consolidation, 1954**

DIRECTOR'S OFFICE

Director: Raymond Price

Divisions of Research:

Timber Management—

J. H. Buell, Chief

Forest Diseases—

L. S. Gill, Chief

Forest Insects—

N. D. Wygant, Chief

Forest Utilization—

L. A. Mueller, Chief

E. S. Kotok

Range Management—

E. H. Reid, Chief

Watershed Management—

M. D. Hoover, Chief

Soils Investigations:

J. L. Retzer

RESEARCH CENTERS

Arizona:

Fort Valley, Flagstaff

E. M. Gaines, Leader

Timber Management—

E. M. Gaines

F. R. Herman

E. C. Martin

Range Management—

J. F. Arnold

Santa Rita, Tucson

H. G. Reynolds, Leader

Range Management—

H. G. Reynolds

J. W. Bohning

Cooperating ARS—

H. M. Hull

M. E. Roach

Sierra Ancha, Tempe

H. C. Fletcher, Leader

Watershed Management—

H. C. Fletcher

L. R. Rich

D. R. Cable

Cooperating ARS—

F. Lavin

Colorado:

Continental Divide, Fort Collins

B. C. Goodell, Leader

Timber Management—

R. R. Alexander

Watershed Management—

B. C. Goodell

Front Range, Fort Collins

L. D. Love, Leader

Range Management—

W. M. Johnson

Cooperating ARS—

G. E. Klipple

Watershed Management—

L. D. Love

Upper Colorado, Delta

G. T. Turner, Leader

Range Management—

G. T. Turner

Watershed Management—

H. E. Brown

Nebraska:

Prairie Research Project, Lincoln

R. A. Read, Leader

Timber Management—

R. A. Read

New Mexico:

Upper Rio Grande, Albuquerque

E. J. Dortignac, Leader

Fire—

A. W. Lindenmuth, Jr.

Range Management—

H. A. Paulsen, Jr.

Watershed Management—

E. J. Dortignac

E. H. Palpant

Wyoming:

Big Horn, Laramie

R. M. Hurd, Leader

Range Management—

R. M. Hurd

F. W. Pond

**FOREST INSECT AND DISEASE
LABORATORIES**

Albuquerque, New Mexico

J. W. Bongberg, in charge

Forest Diseases—

S. R. Andrews

F. G. Hawksworth

T. E. Hinds

Forest Insects—

J. W. Bongberg

R. K. Bennett

Fort Collins, Colorado

B. H. Wilford, in charge

Forest Diseases—

R. W. Davidson

Forest Insects—

B. H. Wilford

C. L. Massey

W. F. Bailey

A. E. Landgraf

R. H. Nagel

F. B. Knight

F. M. Yasinski

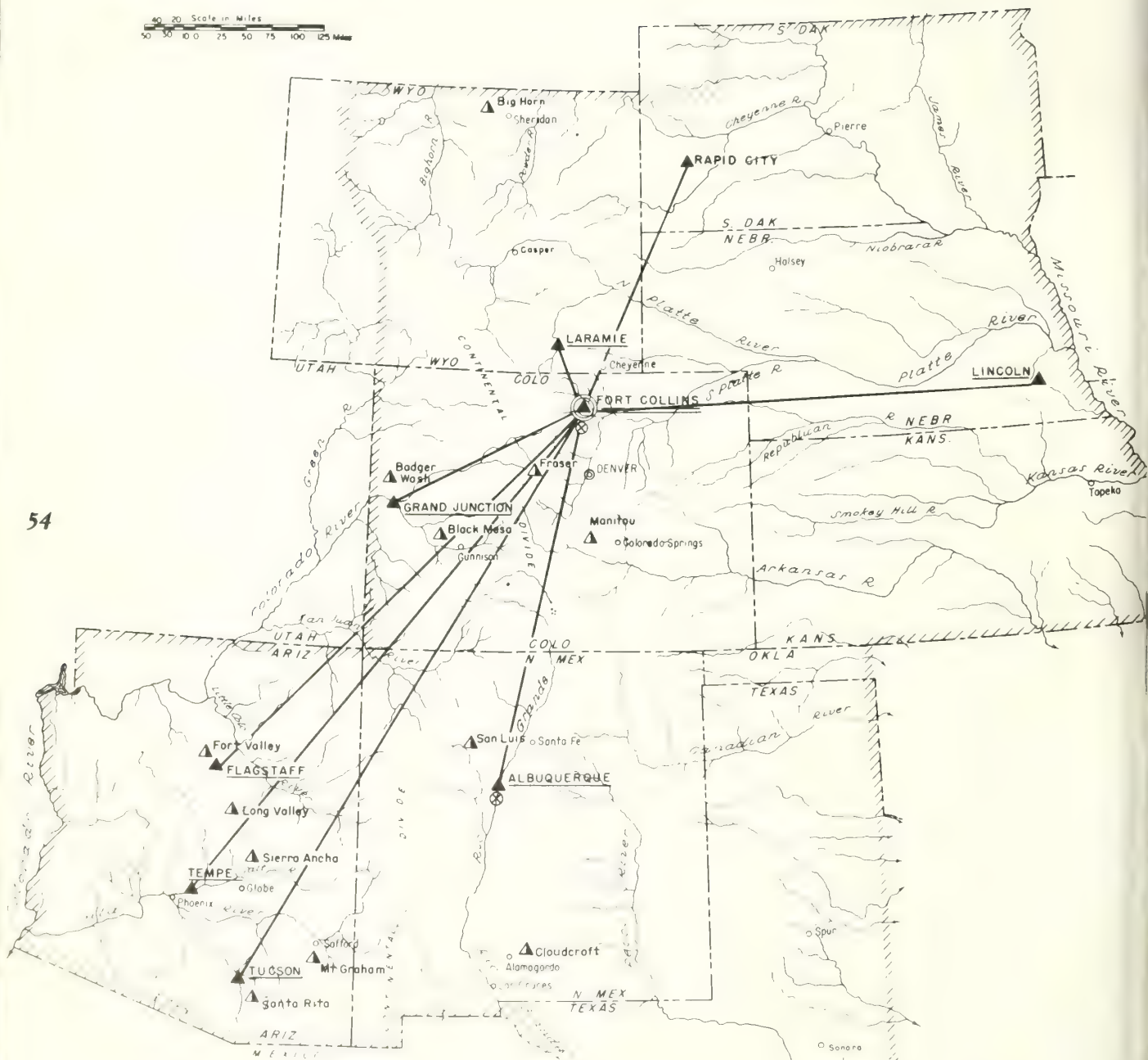


U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

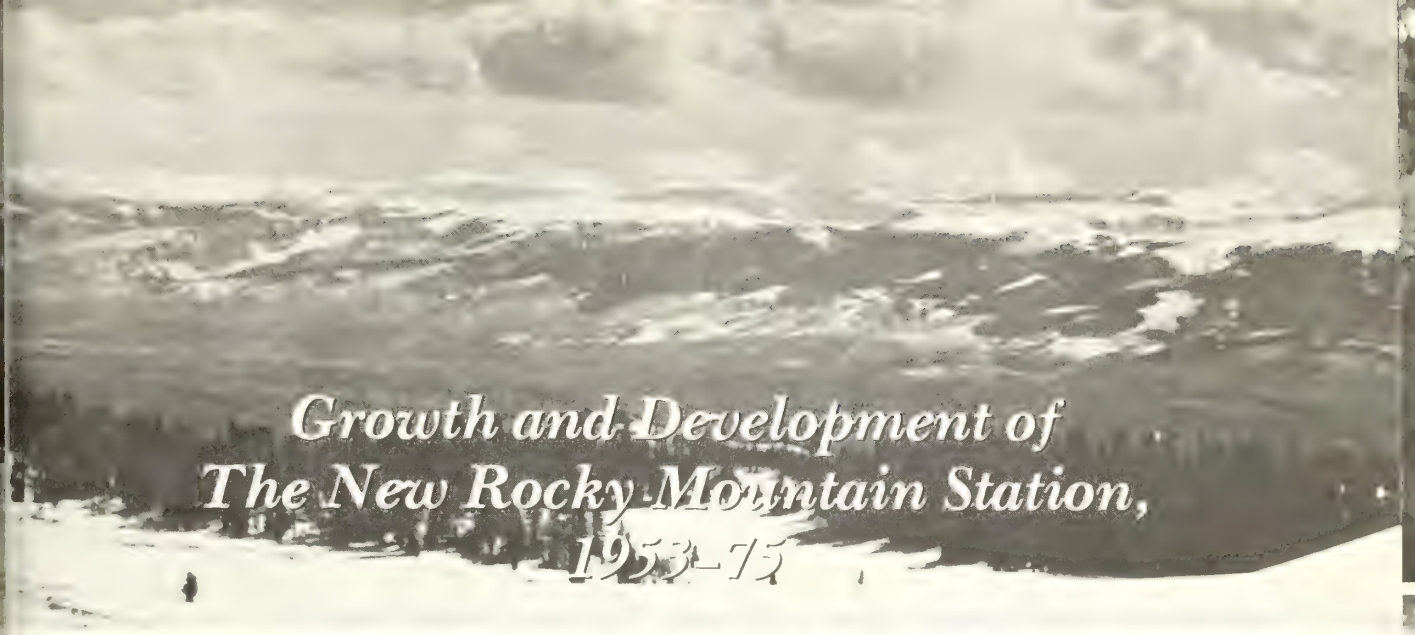
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LEGEND

- Headquarters
- Field Unit Headquarters
- Experimental Areas
- Forest Insect & Disease Laboratory
- Boundary Line



Growth and Development of The New Rocky Mountain Station, 1953-75



From Canada to Mexico, the Rocky Mountain Empire straddles the Continental Divide—the backbone of the country. Much of the area is too steep, too cold, or too arid for cultivation; yet, water for half of the Nation flows from it. A large portion of this empire falls within the jurisdiction of the consolidated Rocky Mountain Station. As demands for water, timber, forage, wildlife, and outdoor recreation increased, the need for forestry research became more urgent. To provide the know-how for continued wise use of the invaluable renewable resources in the heart of the Nation's last wildland frontier was the challenge. With the functioning of its several research centers located



throughout the enlarged area, the new Rocky Mountain Station became recognized as a major wildland resource institution in the Rocky Mountain Empire.

An Expanding Research Program

In response to the increasing needs and challenge, the new Station, with additional appropriated funds, broadened its research program during the remainder of the 1950's, and began some new studies.

Arizona Watershed Program

A significant new activity was the development of the Arizona Watershed Program, including the Beaver Creek Multiple Use Evaluation Project. The results of the watershed studies at the Fraser Experimental Forest in Colorado and the Sierra Ancha Experimental Watersheds in Arizona sparked an interest in water users in Arizona as to how to obtain more water from natural rainfall on the watersheds. The University of Arizona was requested to study the problem as it pertained to the Salt River watershed in central Arizona. Dr. George Barr, head of the Agricultural Economics Department, was given the assignment. He invited several watershed experts to come to Arizona to inspect the watershed. Most of these watershed experts were or had been employed by the Forest Service, since the Forest Service pioneered watershed research and watershed management. Each visiting expert was flown over and driven through the watershed, after which he filed a report of his findings and recommendations. Dr. Barr and his staff reviewed and summarized the reports and prepared a two-part publication entitled "Recovering Rainfall," known as "The Barr Report."

In essence, the "Barr Report" stated that a significant amount of rainfall, in the form of streamflow, could be recovered from the watersheds by various treatments of the vegetation, such as heavier timber harvesting, eradication of pinyon-juniper, and burning brush and other vegetation.

The publication was announced and presented at a special dinner at the Westward Ho Hotel in Phoenix in December 1956. Following the meeting, a Citizen's Committee was appointed, and all was set to begin large-scale watershed treatments. But, land managers raised questions and conservationists objected. They feared that unplanned harsh treatment of the vegetation on the watersheds would wreak havoc and result in irreparable damage. Both the Committee and land managers appealed to the Arizona Congressional Delegation, chiefly Senator Carl Hayden, the dean of the U.S. Senate and Chairman of the Appropriations Committee. Senator Hayden called R. E. McArdle, Chief of the Forest Service, and asked if it would be possible to apply the proposed watershed treatments on a selected watershed on a trial basis to see what would happen before launching a widespread program. McArdle said yes. From then on, the Forest Service, and more particularly the Rocky Mountain Station, were committed. Funds were authorized, the telephone from Washington rang, and the ball began to roll!

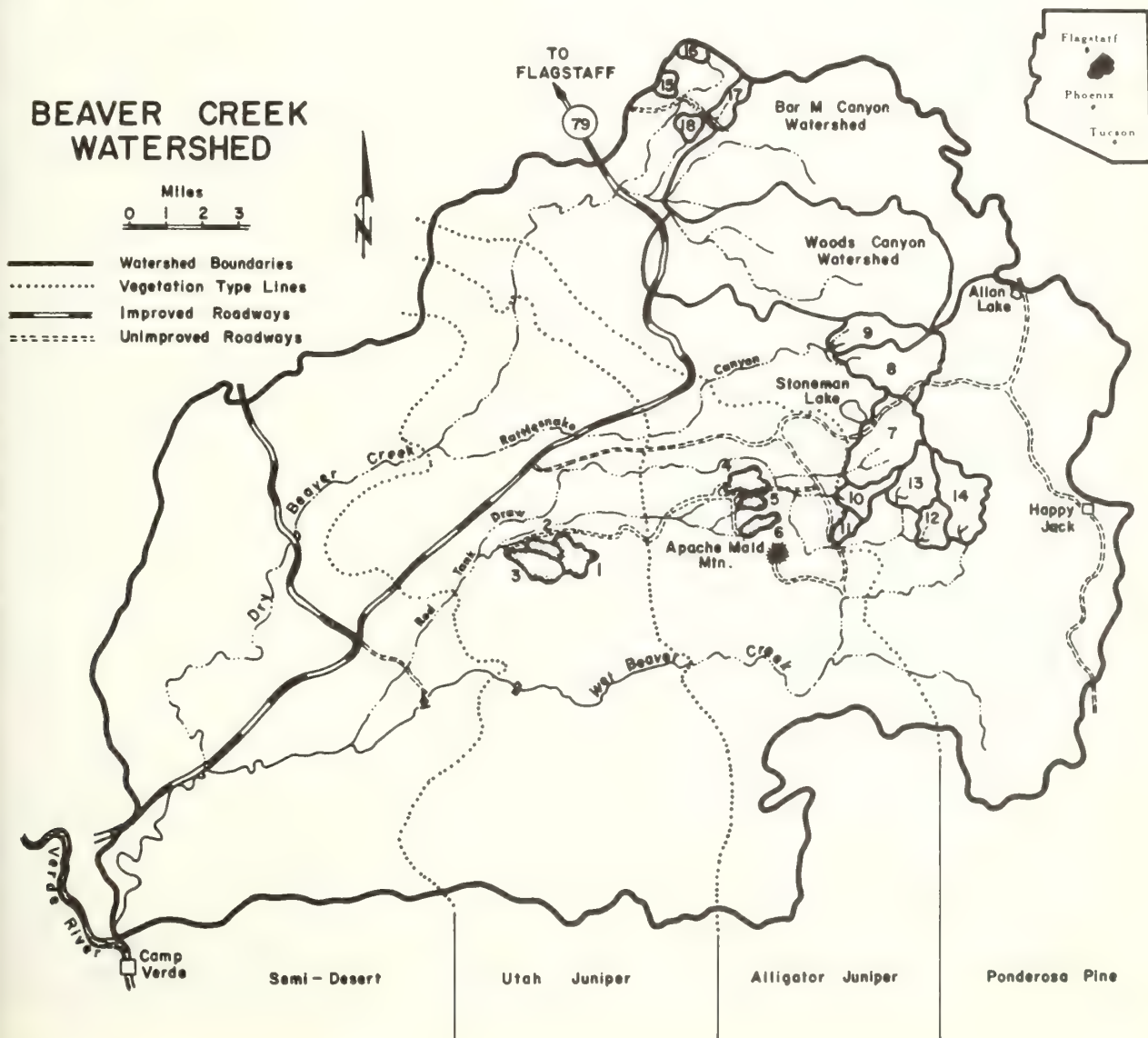
The first step was to find a suitable test watershed. The Beaver Creek watershed on the Coconino National Forest, an upstream tributary of the Verde River—a part of the Salt River System—had been recommended as a segment of a Soil Conservation District program. This large watershed covers some 275,000 acres, and includes ponderosa pine, Utah juniper, and semidesert types—all characteristic of most southwestern watersheds. It was decided to examine it as a possible test area.

Aerial view of the 275,000-acre Beaver Creek experimental area selected for the Multiple Use Evaluation Project.





Aerial view of Beaver Creek watershed 9 (left) with regular strip cutting and no thinning, and of watershed 14 (right) with irregular strip cutting and thinning.



M. D. Hoover, who had recently transferred to the Station in charge of watershed management research, was assigned to represent the Station and look over the Beaver Creek watershed. He met Region 3 people at Flagstaff and spent 2 to 3 days hiking over the watershed since there were no roads.

The inspection party recommended the Beaver Creek watershed as a test area. It had two main drainages—Wet and Dry Beaver Creeks—and some 15 to 20 small subwatersheds, several in each vegetation type. So, as far as the Region was concerned, everything was ready to go. Regional Forester F. R. Kennedy was about to call McArdle and say all was ready to start treatment. Their plan was to treat the whole area and see what would happen. But, the Station said, "It isn't that simple!" After a lengthy telephone conversation, it was agreed that representatives of the Station and the Region should meet and iron out the differences.

The Cory Hotel Match.—Regional Forester Kennedy and W. L. Hanson, Chief Watershed Management, Region 3, and Director Price and Hoover met early one morning at the Cory Hotel, Denver, Colorado, prior to Kennedy's leaving for Washington. Needless to say, when two Irishmen got together to debate a problem, the going was hard and heavy! By midafternoon the air cleared. All present agreed that simply treating the whole area was not the plan to follow—that the area had to be stratified, and that the effects of the proposed treatments in the different vegetation types might vary considerably. Moreover, replication of treatments was essential to furnish sound information; also that the proposed treatments (various patterns of timber harvest, pinyon-juniper control, and reseedling) should be applied to one of the two main drainages, leaving the other drainage for a later large operational program. Hence, the Beaver Creek Multiple Use Evaluation Project was launched and has been carried forward essentially as ironed out at the Cory Hotel.

The Beaver Creek story is a long one—too long to record here. Moreover, it will not end soon because additional results will continue to become available as other treatments are applied and the years go by. It is a unique project—first and only one of its kind anywhere. It has received worldwide attention. The Forest Service, Region 3, the Rocky Mountain Station, and supporters may well be proud of this most significant contribution to forest land management.



Some of the Men Involved.—Many people have and will be involved in the Beaver Creek Project. Names have and will appear on reports and publications of the findings. It is beyond this history to mention them all, but a few are listed here in order to name some of those who shared the initial responsibility. For Region 3 were Regional Forester F. R. Kennedy and his successor W. B. Hurst; W. L. Hanson and his successors L. B. Woods and G. R. Proctor; and Supervisors R. W. Crawford, J. H. Cravens, R. M. Housley, and D. D. Seaman of the Coconino National Forest. For the Station, in addition to Director Price and M. D. Hoover, in chronological order, were E. F. Aldon, D. P. Worley, H. E. Brown, R. D. Lloyd, D. E. Herrick, and D. R. Carder. Those in charge of associated projects in the Arizona Watershed Program were L. R. Rich and J. R. Thompson, pine-fir forest watersheds; G. E. Glendening and A. R. Hibbert, chaparral and woodland watersheds; J. S. Horton, riparian and phreatophyte areas; and P. F. O'Connell, evaluation of watershed programs.

*Beaver Creek watersheds,
Coconino National Forest,
Arizona:*

*(Left) Measuring water
yield and silt content.*

*(Upper right) Killing pin-
yon and juniper to deter-
mine the effect on water
yield, livestock forage, and
wildlife habitat. (Below)
Testing strip cutting to de-
termine changes in water
yield.*



Other Accomplishments

Going research was intensified on all fronts. A few examples include (1) radioactive tagging of Engelmann spruce beetles in Colorado to provide basic information on dispersion and flight habits of this destructive insect (R. H. Nagel); (2) the use of nematodes to reduce egg production of Engelmann spruce beetles (C. L. Massey); (3) ballistics studies of dwarf mistletoe seeds (F. G. Hawksworth and T. E. Hinds); (4) work on native stem rusts of pines (R. S. Peterson); (5) the establishment of a groundwood pulpmill in Arizona and the construction of a charcoal kiln in Colorado to

study kiln schedules and designs suited to local species (L. A. Mueller and E. S. Kotok); (6) spruce management and artificial regeneration in beetle-killed spruce stands (R. R. Alexander and F. Ronco); and (7) levels of grazing and the effects of pocket gophers on vegetation and soils on Thurber fescue range (G. T. Turner).

A, W. M. Johnson, and

B, Raymond Price, conducting training sessions at Manitou Experimental Forest, Colorado.

C, R. A. Read, examining (left) nursery seedlings, and (right) an experimental shelterbelt planting. Tree in foreground, and those in background, are same species and age, but come from different seed sources, Horning Farm, Nebraska.

D, R. M. Nagel, selecting beetles to be equipped with aluminum foil harnesses for study of flight habits.

E, C. A. Myers, developing computerized techniques to speed timber management planning, and to reduce costs. Fort Collins, Colorado.

F, R. R. Alexander, checking the growth response of Engelmann spruce within a timber measurement plot. Roosevelt National Forest, Colorado.

G, W. F. McCambridge, studying life habits of mountain pine beetles. Fort Collins, Colorado.

H, F. G. Hawksworth, observing dwarf mistletoe infection. Roosevelt National Forest, Colorado.

I, F. Ronco, determining physiological response of Engelmann spruce seedlings. Fort Collins, Colorado.

J, M. D. Hoover, measuring changes in sap flow to determine peak periods of moisture use. Fraser Experimental Forest, Colorado.



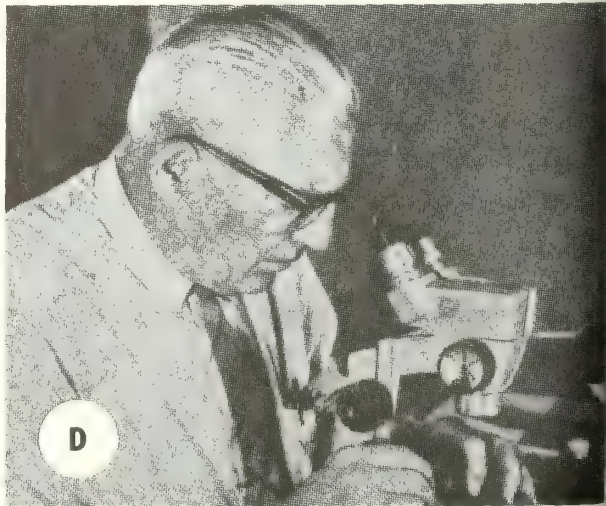
A



B



C



D



Black Hills Research Center.—Another major achievement was the establishment of the Black Hills Research Center in 1955. For years the lumber industry in the Black Hills was largely on a saw-log basis. The trees were cut and sawed into boards and shipped out of the area. Little or no remanufacturing was done. Moreover, the smaller stems and other material were left unused in the woods. With the interest of the Governor of South Dakota and a Forest Utilization Committee established in Rapid City, supported by Senator Karl E. Mundt, the Congress appropriated funds to establish a Forest Research Center in the Black Hills. Emphasis was to center on ways and means of developing new wood-using industries. However, funds were sufficient to begin supporting studies in timber growth and production, watershed improvement, and improved range-wildlife habitat. The decision was made to locate the research unit in Rapid City in cooperation with the South Dakota School of Mines and Technology where some library and research interests were present. Offices were made available in the old Prep Building on the campus.

R. M. Hurd was transferred from Laramie to head up the Research Center. Other scientists and the fields of research undertaken were:

**Organization of the Black Hills
Research Center, Rapid City, South Dakota,
1955**

R. M. Hurd, Leader
Research Projects:

Timber Management—

C. A. Myers

Forest Utilization—

E. F. Landt

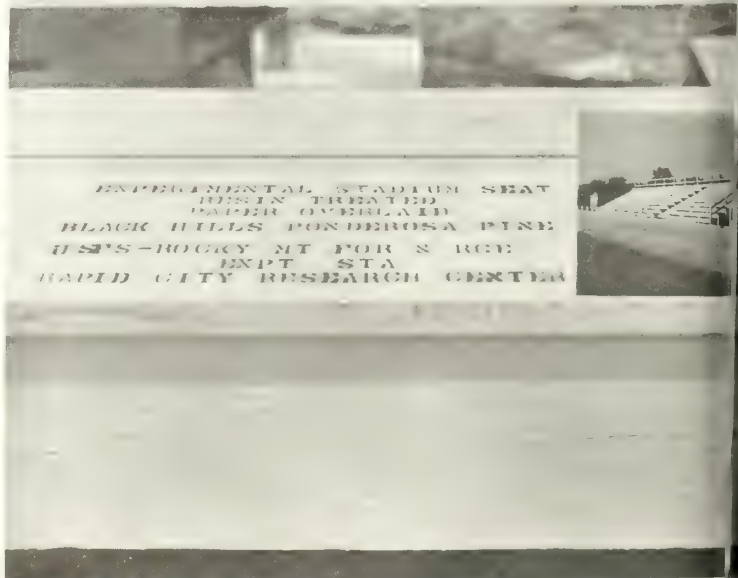
R. O. Woodfin

Range Management—

C. P. Pase

Watershed Management—

H. K. Orr



(Upper right) Stadium seats were overlaid with resin-treated paper for service testing, South Dakota School of Mines and Technology, Rapid City.

(Left) Chemicals were used in peelability tests on Black Hills ponderosa pine, South Dakota.

(Lower left) Black Hills ponderosa pine fenceposts, treated by nine different methods.



Other new studies begun during the 1950's included the following:

Forest Fire Research.—When A. W. Lindenmuth, Jr. completed his assignment in Albuquerque, developing an improved fire-danger system for the Southwest, he was transferred to Fort Collins in 1955 to begin fire-danger studies Stationwide.

Skyline Crane Logging.—In furthering the proper utilization of steep slope timberlands, Mueller and Kotok, assisted by F. R. Herman, completed arrangements for the purchase of an overhead cable system (Wyssen) in 1955. They also arranged for Mr. Wyssen, the Swiss designer and maker of the system, to install the equipment for testing at the Fraser Experimental Forest. Harvesting these idle forest stands would not only permit the utilization of timber which otherwise would be lost, but also foster management of the steep watersheds by opening up the stands for increased snowpack. Moreover, such a method of logging would reduce erosion and eliminate costly access roads.

(Upper left) C. P. Pase, measuring streamflow changes that result from vegetation changes on chaparral watersheds. Tonto National Forest, Arizona.

(Lower left) L. A. Mueller, testing moisture content in structural wooden beams. Fort Collins, Colorado.



(Upper right) A. W. Lindenmuth, Jr., determining rate of spread of prescribed fires, Arizona.

(Lower right) Testing use of skyline crane logging 63 in the Rocky Mountains. Fraser Experimental Forest, Colorado.

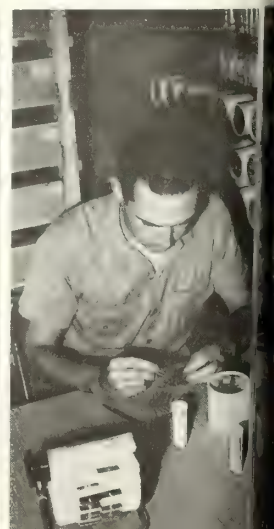


Alpine Snowfields.—In further recognition of the great value of the water resources of the Rocky Mountain Empire, studies on the influence of alpine snowfields—upstream reservoirs—on streamflow were begun. M. Martinelli, then a graduate student at New York State University, working with B. C. Goodell at Fraser, made a survey of alpine areas of the Front Range in 1954 and studied the "Hydrology of Alpine Snowfields" for his Ph.D. thesis. This began what developed into a major field of research for the Forest Service.



(Upper right) Building snowfence near Loveland Pass, Colorado, to help keep blowing snow out of an avalanche path; (below) R. W. Hanson and R. E. Stillman, determining snow accumulation on each side of a snow fence.

(Upper left) M. Martinelli, Jr., testing snow strength with a torque wrench and vane; (below) Elnora Martinelli, obtaining snow sample to determine water equivalent.



(Lower right) F. M. Yasinski (in field) and M. E. McKnight (in mobile laboratory), checking for spruce budworm infestation.





(Left) Check dams of loose rock, reinforced by woven wire were used to control erosion. Manitou Experimental Forest, Colorado.



(Right) Conifer seedlings in the nursery grew faster when provided with supplemental light at night. Lincoln, Nebraska, 1957-58.

Effects of Pocket Gophers on Rangelands.—A cooperative research program was begun in 1955 with the Colorado Agricultural Experiment Station, the U.S. Fish and Wildlife Service, and the Colorado Cattlemen's Association to study the effects of pocket gophers on range vegetation and watershed values and to develop methods of control under field conditions. G. T. Turner represented the Station.

Forest Survey and Forest Economics.—The National Forest Survey was begun in Colorado and Wyoming in 1955. The work was in cooperation with the Forest Survey Unit at the Intermountain Station. Forest Survey in the Black Hills and in Nebraska and Kansas was handled by the Lake States Experiment Station. In 1956, M. E. Becker was assigned to the Station to begin economic studies focusing on finding new markets to expand use of overmature lodgepole pine. Becker was replaced by C. R. Hathaway in 1958. J. M. Hughes replaced Hathaway in 1959.

San Luis Cooperative Range-Watershed Study.—In 1955, E. J. Dortignac completed arrangements with the U.S. Bureau of Land Management and the U.S. Geological Survey to begin a cattle grazing-watershed study near the community of San Luis, New Mexico. Grazing was conducted during a 6-month winter season, and forage production, siltation, and water yield were measured.

Increasing Skills to Assist the Expanding Program

It soon became evident that supporting skills were necessary to assist in the expanding research program of the new Station. Hence, in 1955, E. W. Shaw, a forester at the Pacific Northwest Station with an interest in writing, transferred to the Station as Editor. Shaw, with his background and training in forestry, was of material assistance to the scientists in writing up their findings. He also conducted training programs

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Experimental harvests, 1958-66, in Arizona's mixed conifer forests to determine effects on water yield. Workman Creek, Sierra Ancha Experimental Forest.



for the scientists less experienced in writing. Shaw left the Station in 1962. R. H. Hamre, a chemistry and journalism major from the University of Wisconsin, then transferred to the Station from the Forest Products Laboratory. Hamre broadened the scope and, with the introduction of new equipment and the expansion of printing and photographic facilities at Colorado State University, improved the format and readability of the Station publications and releases.

In 1956, J. L. Kovner, a forest soils major with special abilities in statistics, transferred from the Southeastern Station as Station biometrician. Kovner was tremendously helpful to the other scientists in the design of experiments, computing techniques, and analyses of data. As

the work progressed and the program of the Station grew in scope and complexity, others were added to the biometrics group including G. Peterson, G. L. Godsey, C. D. Adair, B. J. Erickson, and G. E. Brink.

To assist in the administration of the expanding program, D. M. Ilch was transferred to the Station in 1958 as Chief of Station Management. Ilch came from the Internal Audit Unit headquartered in the Washington Office. Ilch was assisted by D. E. Bradfield until 1961 when Bradfield retired.

With the increase in personnel, D. H. Morton was transferred from the Regional Office in Denver in 1962 to handle personnel services and

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Stationwide Research Program Conference

Globe, Arizona—February 26-27, 1957

(Left to right)

First row: E. F. Landt, F. Ronco, B. C. Goodell, H. K. Orr, D. S. Nordwall (R-2), L. A. Mueller, M. M. Larson, E. C. Martin, D. A. Jameson, A. W. Lindenmuth, Jr., J. L. Kovner, E. J. Dortignac, L. D. Love, G. L. Hayes, D. E. Bergstrom, R. H. Nagel, E. H. Reid.

Second row: J. L. Retzer, H. Camp (INT), M. E. Becker, R. O. Woodfin, Jr., B. Reed (R-2), B. H. Wilford, A. E. Landgraf, E. W. Shaw, C. P. Pase, E. F. Aldon, E. H. Palpant, W. C. Hickey, Jr., L. S. Gill, R. R. Alexander, C. A. Myers, S. R. Andrews, L. R. Rich, D. R. Cable.

Back rows: H. G. Reynolds, D. A. Pierce, Director Raymond Price, J. W. Bohning, R. W. Davidson, R. M. Hurd, G. T. Turner, F. R. Herman, F. W. Pond, E. M. Gaines, J. P. Daniels, J. A. Wagar, W. M. Johnson, R. E. Johnson, D. E. Bradfield, J. S. Horton, F. B. Knight, W. M. Curtis, H. W. Berndt, J. O. Keith, R. M. Hanson, H. E. Ostmark, H. E. Brown, R. A. Read, J. P. Decker, F. M. Yasinski, C. L. Massey, H. L. Gary, V. H. Reid (Cooperator, U.S. Fish & Wildlife Service), M. Martinelli, Jr., S. C. Martin, M. D. Hoover, H. A. Paulsen, Jr.

(Absent were E. M. Conway, D. K. Smith, H. W. Springfield, and N. D. Wygant.)



budgetary matters formerly handled by Bradfield. As the personnel workload grew, T. T. Hahn was added to the staff in 1968 as full-time personnel officer. In 1972, Hahn transferred to Washington, D. C., and L. L. Manley transferred from the National Finance Office to assume the personnel duties.

In addition to the special skills added to the Station, Director Price, using in part the authority of the Government Employees Training Act, PL 85-507, inaugurated a program of graduate study and self-betterment of Station personnel. The Rocky Mountain Station led out in these fields. Up to 20 scientists per year were engaged in graduate study under the training program. About 75 percent of the technical staff obtained advanced degrees, one-fourth of whom completed their doctorates. Of the 86 scientists on the Station staff in 1975, 76 (86 percent) have advanced degrees; 40 (47 percent) of these are Ph.D.'s. Having the research centers located with colleges and universities facilitated the training and self-betterment program.

Facilities to Sustain the Research Program

The growth of the new Station soon outgrew the available research facilities. Office space became critical for Station personnel as the growth of the colleges and universities overtaxed their facilities.

As part of a nationwide program, the Station began a building campaign. In total, seven new research facilities, complete with modern offices, laboratories, greenhouses, and libraries, were constructed during the sixties and early seventies. This included a headquarters building at Fort Collins. D. M. Ilch, Division Chief of Station Management, spearheaded the building program.

The first of these facilities was the Forest Research Laboratory at Rapid City, South Dakota, dedicated May 21, 1960. How this facility was obtained is interesting. When the Black Hills Research Center was established, President F. L.

Partlo, South Dakota School of Mines and Technology, said, "We just don't have any space available. We are a small institution, and our facilities budget is nonexistent. The only possible quarters available is the top floor of the old Prep Building which has been condemned!" It was a small, three-story structure. Part of the first floor was being used by the U.S. Geological Survey for recording instruments. The band practiced on the second floor. A narrow, rickety stairway led to the third floor, which was totally abandoned.

After looking over the building, and with an eye to the future, the Station said, "We'll take it!" After a month or so with carpenters and painters, the quarters, once one got to them, were tolerable but there were no laboratory facilities.

The next summer Senator Karl Mundt of South Dakota was making rounds with his constituents. President Partlo was prevailed upon to invite the senator to the campus to see the new Forest Research Center. The day was hot and muggy. By the time the senator climbed the narrow rickety stairs to the third floor, he was out of breath and perspiring. He sat down on the first available chair, wiped his brow, and asked, "Is this the best you've got?"

In the next session of Congress, \$100,000 was earmarked for a Forest Research Laboratory at Rapid City, South Dakota. Time for the customary legislative procedures was not sufficient. So the senator, being a member of the Senate Appropriations Committee, earmarked \$100,000 of a million-dollar appropriation item for a forest fire laboratory for Missoula, Montana, for a laboratory at Rapid City. Needless to say, Chief L. F. Watts and the fire researchers at Missoula were not too happy. But, the Station got a laboratory—an attractive addition to the college campus. A special invitation to the dedication was sent to the Missoula fire researchers!

The obtaining of funds and the construction of the remaining six forestry laboratories within the Station area, including the headquarters office-laboratory at Fort Collins, were equally interesting and stimulating. Several members of

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*Forest Research Laboratory,
Rapid City, South Dakota,
dedicated May 21, 1960.*



the Appropriations Committee of the U.S. Senate hailed from the Station area, and were acquainted with forestry resources and needs. These included Karl E. Mundt of South Dakota, Carl T. Curtis of Nebraska, Gale W. McGee of Wyoming, Gordon L. Allott of Colorado, Dennis Chavez and Clinton P. Anderson of New Mexico, and Carl Hayden of Arizona. Senator Hayden served as chairman of the committee for several years. He had firsthand knowledge of the Nation's natural resources, especially of the West, and championed their development and management, including the necessary supporting research and facilities.

All of the office-laboratories were located on college or university campuses where library and related research facilities and interests were available. This was done under formal Cooperative Agreements whereby the State institutions provided the lands and the Federal Government constructed the facilities—a mutually beneficial arrangement.

The Forestry Sciences Laboratory at Flagstaff was located on the campus of Arizona State College, now Northern Arizona University. It was dedicated May 21, 1963. Prior to that time, Station personnel were first officed in temporary wartime barracks on the campus and then on the second floor of the Journalism Building.

68 The Forest, Range, and Watershed Laboratory at Laramie, on the University of Wyoming campus, was also dedicated in 1963, on May 23. Previously, Station personnel were officed in the Agriculture building. For a short time, one of the scientists from the Big Horn Research Center was officed at Northern Wyoming Community College at Sheridan.

The Forest Hydrology Laboratory (Tempe) was dedicated December 16, 1965. Under a three-way Memorandum of Understanding among the University of Arizona (the Land Grant authority in Arizona), Arizona State University, and the Station, the new laboratory was located on the Arizona State University campus at Tempe. Prior to the completion of the laboratory, Station personnel were officed in two different buildings on the Arizona State campus in cooperation with the University's Agriculture Department. The Station built a small office-laboratory near the Agriculture building for its use. When the new laboratory was completed, this structure was razed to make room for campus improvements.

The Headquarters office-laboratory at Fort Collins, on the Colorado State University campus, was dedicated July 28, 1967. Except for the first year, 1935, when Station personnel were temporarily located on the top floor of the Administration building, the Station had occupied part of the second floor of the College's then-new Forestry

building. As the new Station grew, additional space was occupied in two other College buildings, Student Services, and South Hall, a wartime temporary structure now removed. Also, office space was rented in D. C. Royer building in downtown Fort Collins. At the time of the dedication of the Headquarters office-laboratory, President William E. Morgan, Colorado State University, referring to the long-time and increasing space requirements of the Station, quipped, "It was like the man who was invited to dinner—he came with his family and stayed!"

It took several years to get the Forestry Sciences Laboratory at Lincoln. Plans and drawings were completed in 1968, but the building was not constructed and dedicated until October 19, 1973. It is located on the East Campus of the University of Nebraska.

Under a three-way Memorandum of Understanding among New Mexico State College (now New Mexico State University) at Las Cruces (Land Grant authority for New Mexico), the University of New Mexico at Albuquerque, and the Station, building space was made available to the Station for an office-laboratory at the Research Park of the University of New Mexico in Albuquerque. Funds were appropriated for planning the facility. The plans were completed, but to date funds have not been appropriated for the construction of the building. Station personnel were officed on the university campus in a wartime temporary structure, and then in Marron Hall. Space became critical on the campus so when the new Federal Office Building in downtown Albuquerque was constructed, space was made available in the building for the Station. The Station added a small greenhouse on the roof of the building.

At the time the University of Arizona acquired the Tumamoc Hill property in Tucson from the Federal Government by exchange and purchase (1960), they agreed to continue to furnish suitable office and laboratory space for Station personnel in Tucson. Hence, the Station people remain on Tumamoc Hill in part of the buildings formerly occupied by the Southwestern Station.

The Shelterbelt Laboratory at Bottineau, North Dakota, on the campus of the North Dakota School of Forestry, was built in 1963 as part of the nationwide building program. It was a facility of the Lake States Experiment Station, but in 1966 became a part of the Rocky Mountain Station.

Thus, the building program inaugurated in the late fifties essentially was completed. All field units and central headquarters of the Station were provided and equipped with office and laboratory facilities.



<i>Laboratory location</i>	<i>Dedication date</i>
A, Flagstaff, Arizona	May 21, 1963
B, Laramie, Wyoming	May 23, 1963
C, Tempe, Arizona	December 16, 1965
D, Fort Collins, Colorado	July 28, 1967
E, Lincoln, Nebraska	October 19, 1973
F, Tucson, Arizona	(Exchange) 1960
G, Bottineau, North Dakota	(Transfer) 1966



Project Orientation and In-Depth Research

With the planning and completion of adequate research facilities, the total program of the Station was reappraised in the early 1960's as part of a Servicewide reorganization of research.

The term "research center leader" at field units was abandoned. Field locations were maintained, but the research was organized on a project or subject-matter basis. Where a project was undertaken was determined on three criteria: (1) where the problem could best be attacked, (2) where suitable library and research facilities were available, and (3) where cooperation was assured. Hence, subject-matter research became dominant rather than location.

The research was organized into projects led by "Project Leaders," who were subject-matter specialists. One project leader at each field location was designated to handle overall administrative and cooperative matters, in consultation with the other project leaders. As occasion warranted, this administrative responsibility was rotated to other project leaders.

New projects added to the Station program in the 1960's included:

Range Biometry.—M. J. Morris, Project Leader. This westernwide project was designed to develop improved methods and techniques in range research. Morris transferred to Fort Collins from the Intermountain Station.

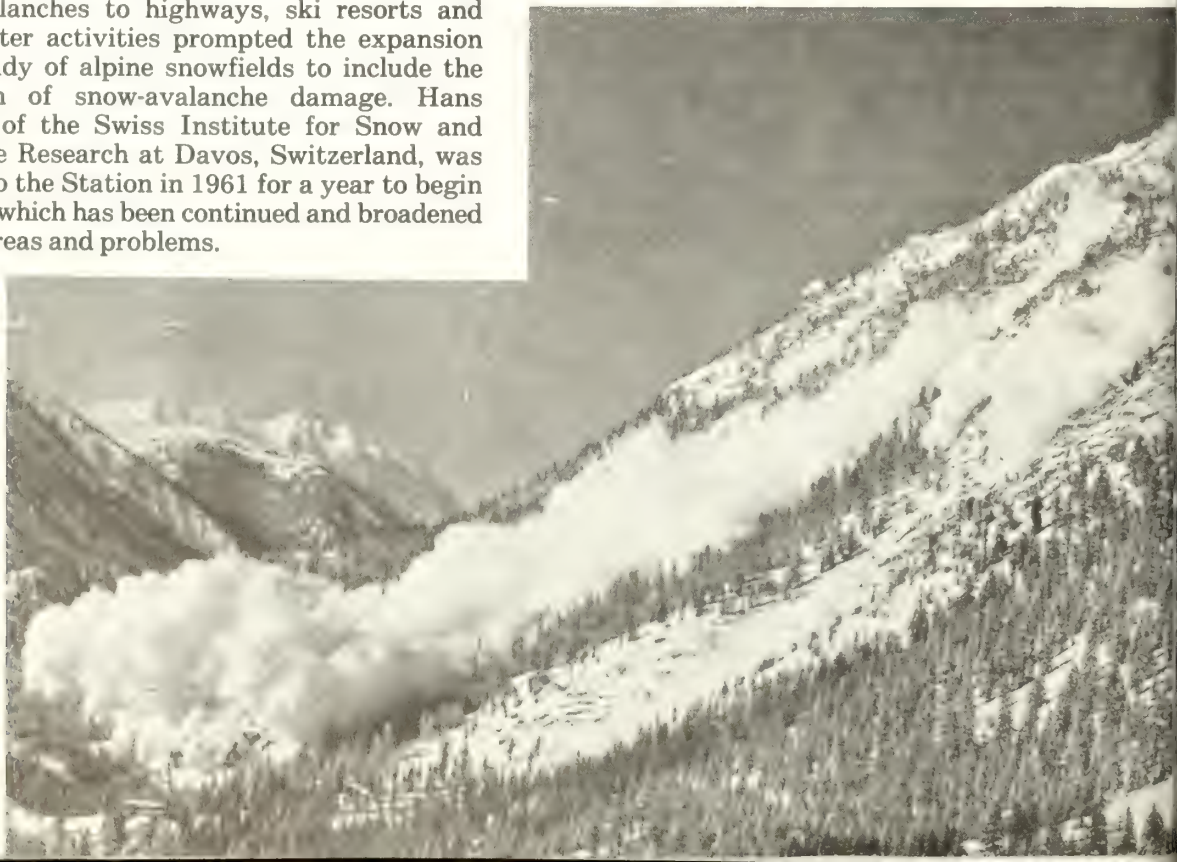
Snow Avalanche Research.—M. Martinelli, Jr., Project Leader. The increasing problem of snow avalanches to highways, ski resorts and other winter activities prompted the expansion of the study of alpine snowfields to include the alleviation of snow-avalanche damage. Hans Frutiger, of the Swiss Institute for Snow and Avalanche Research at Davos, Switzerland, was brought to the Station in 1961 for a year to begin the study which has been continued and broadened to other areas and problems.

Forest Recreation.—L. D. Love, Project Leader. With the great increase in outdoor recreation, the various kinds, location, and concentration of recreational sites and use of the National Forests were evaluated in the central and southern Rocky Mountain region. Love, who had devoted most of his career to watershed management research, began and pursued this new project until his retirement in 1964. H. D. Burke with the assistance of W. D. Beardsley, carried the project until 1966 when the research was transferred to Logan, Utah, under direction of the Intermountain Station.

Mensuration.—C. A. Myers, Project Leader. To quicken and improve the management and use of the timber resources, a special study in computerized management of ponderosa pine in the Black Hills where records were available was begun. Later, Myers directed his special skills and interest to other timber types and problems.

Prairie Grouse Habitat.—D. R. Dietz, Project Leader. K. E. Evans, working under Dietz's leadership, began studies of prairie grouse habitat in the Great Plains to give needed direction and guidance to management and use of this range-wildlife resource.

Many avalanches in the Rocky Mountains start when wind-toughened snow layers, called wind slabs, fracture and slide down the mountains. Twin Lakes, Colorado.





A, E. H. Reid, checking the herbage meter on the Front Range, Colorado.

B, (Left to right) J. R. Thompson, J. B. Ryan, Jr., a summer assistant, and D. M. Ilch, measuring water use by phreatophytes in central Arizona.

C, G. W. Peterson, using sterilizer equipment in studies to control diseases of conifers in nurseries, Lincoln, Nebraska.

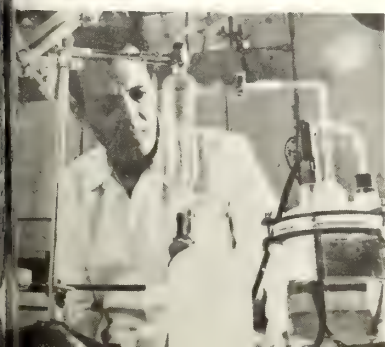
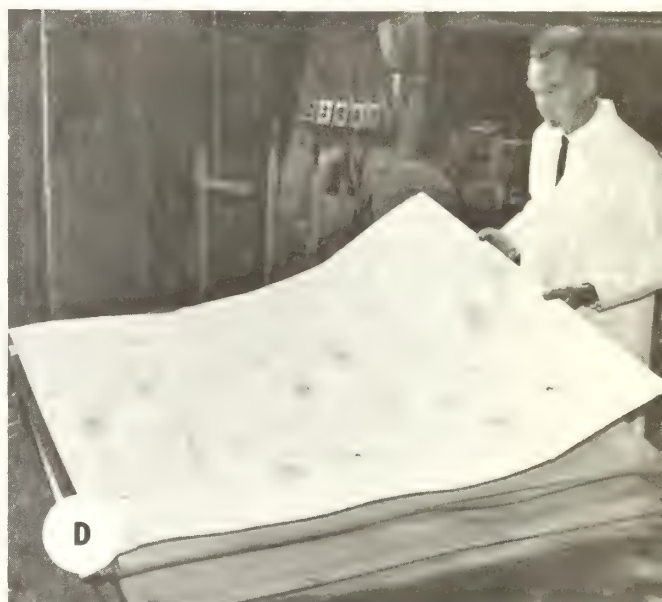
D, R. L. Barger, evaluating veneer cut from grade 5 ponderosa pine saw logs, Flagstaff, Arizona.

E, J. L. Van Deusen, examining ponderosa pine stand in experimental thinning plots of the Black Hills Experimental Forest, South Dakota.

F, H. W. Springfield, obtaining samples for perennial grass density study, New Mexico.

G, D. R. Dietz, determining nutritional status of forage and browse species, Rapid City, South Dakota.

H, Dixie R. Smith and R. D. Tabler, using laboratory equipment in Forest, Range, and Watershed Laboratory at Laramie, Wyoming.



Cooperative Watershed Management Unit.—B. C. Goodell, Project Leader. With the growing importance of watershed management, more personnel trained in watershed science were needed. To help meet this need, the Forest Service established a Watershed Management Unit with the College of Forestry and Natural Resources at Colorado State University. B. C. Goodell was assigned in charge of the Unit which he carried until his retirement in 1968. Goodell conducted special research and directed studies of graduate students in the watershed management field.

Use of Fire in Chaparral.—A. W. Lindenmuth, Jr., Project Leader. As part of the Arizona watershed improvement program, Lindenmuth was transferred to Flagstaff in 1962 to begin intensive study of the effects and use of different types and degree of fire on reduction and control of chaparral.

Other Changes.—G. L. Hayes came to the Station in October 1956 as Chief of Timber Management Research to replace Buell who retired. With his rich background in forest management research, Hayes spearheaded the organization and development of the several research projects, including the training of younger scientists.

Improved laboratory and other research facilities made possible more in-depth research. A team of specially trained scientists was able to focus attention on a particular problem. For example, G. W. Peterson, a trained Plant Pathologist, was added in 1958 to the Shelterbelt Proj-

G. L. Hayes (left), describing silviculture characteristics of a forest stand to D. L. Noble. Roosevelt National Forest, Colorado.



ect at Lincoln, Nebraska, to obtain information and give guidance to the disease aspects of this project. The Whitten Amendment to the Granger-Thye Act (64 Stat. 82, as amended April 16, 1956) fostered and stimulated participation from State and other public and private agencies in forestry research. During this same period, in 1961, the Forest Insect Survey—previously a part of Forest Insect Research—was transferred to the Regions. B. H. Wilford, W. F. Bailey, and A. E. Landgraf were transferred to Region 2 (Denver), and F. M. Yasinski and A. M. Rivas to Region 3 (Albuquerque).

Projects, Project Leaders, Scientists, and Locations, 1962

ARIZONA

Flagstaff:

Evaluation of Watershed Programs—

D. P. Worley, Project Leader

H. E. Brown

W. P. Clary

A. R. Tiedemann

P. F. Ffolliott

Fire Use—

A. W. Lindenmuth, Jr., Project Leader

J. R. Davis

Management—Woodland and Forest Ranges—

D. A. Jameson, Project Leader

H. A. Pearson

Silviculture—Ponderosa Pine—

G. N. Schubert, Project Leader

M. M. Larson

L. J. Heidmann

E. C. Martin

Tempe:

Management—Chaparral Ranges—

F. W. Pond, Project Leader

H. D. Chadwick (attached to Albuquerque)

Management—Riparian and Wet Sites—

J. S. Horton, Project Leader

J. P. Decker

C. J. Campbell

Water Yield Improvement—Chaparral—

G. E. Glendening, Project Leader

P. A. Ingebo

C. P. Pase

C. M. Skau

Water Yield Improvement—Pine-Fir—

L. R. Rich, Project Leader

P. T. Koshi

Wildlife Habitat—

H. G. Reynolds, Project Leader

Tucson:

Management—Semidesert Ranges—

S. C. Martin, Project Leader

D. R. Cable

COLORADO

Fort Collins: (* indicates acted as Project Leader in addition to Division Chief responsibilities)

Forest Diseases—

Diseases—Montane and Subalpine Species—
F. G. Hawksworth, Project Leader
J. M. Staley
T. E. Hinds

Forest Economics—

Forest Survey—
R. L. Miller
Market Development Opportunities—
J. M. Hughes, Project Leader
Forest Recreation—
L. D. Love, Project Leader

Forest Insects—

Biology, Ecology, and Control of Bark Beetles and Defoliators in the Central Rocky Mountains—
N. D. Wygant, Project Leader*
W. F. McCambridge
R. H. Nagel
M. E. McKnight

Timber Management—

Mensuration—
C. A. Myers, Project Leader
Silviculture—Spruce-Fir and Lodgepole Pine—
R. R. Alexander, Project Leader
F. Ronco
Silviculture—Mixed Conifers and Aspen—
G. L. Hayes, Project Leader*
J. R. Jones

Range Management and Wildlife Habitat—

Forest Biometry—
M. J. Morris, Project Leader
Forest Game and Fish Habitat—
Dwight R. Smith, Project Leader
Management—Mountain Ranges
H. A. Paulsen, Jr., Project Leader
P. O. Currie
G. L. Spain

Watershed Management—

Alpine Snow and Avalanches—
M. Martinelli, Jr., Project Leader
A. Judson
Water Yield Improvement; Runoff and Erosion—
M. D. Hoover, Project Leader*
R. H. Swanson
J. D. Bergen
B. H. Heede
E. C. Frank
Cooperative Watershed Management Research Unit—
B. C. Goodell, Project Leader

NEBRASKA

Lincoln:

Diseases—Shelterbelts and Nurseries—
G. W. Peterson, Project Leader
Silviculture—Windbreaks—
R. A. Read, Project Leader
D. H. Sander
D. F. Van Haverbeke

NEW MEXICO

Albuquerque:

Diseases—Ponderosa Pine and Associated Species—
P. C. Lightle, Project Leader
J. W. Riffle
Insects—Biology, Ecology, and Control of Bark Beetles and Defoliators in the Southwest—
C. L. Massey, Project Leader
M. J. Stelzer
J. F. Chansler
Range Improvement and Management of Seeded Ranges—
H. W. Springfield, Project Leader
Watershed Rehabilitation—
E. F. Aldon, Project Leader
W. C. Hickey
Water Yield Improvement—
H. L. Gary, Project Leader

SOUTH DAKOTA

Rapid City:

Forest Utilization (Black Hills)—
E. F. Landt, Project Leader
V. P. Yerkes
Silviculture—Ponderosa Pine (Black Hills)—
C. E. Boldt, Project Leader
J. L. Van Deusen
Water Yield Improvement (Black Hills)—
H. K. Orr, Project Leader
M. L. Geiger
Wildlife Habitat (Black Hills)—
D. R. Dietz, Project Leader

WYOMING

Laramie:

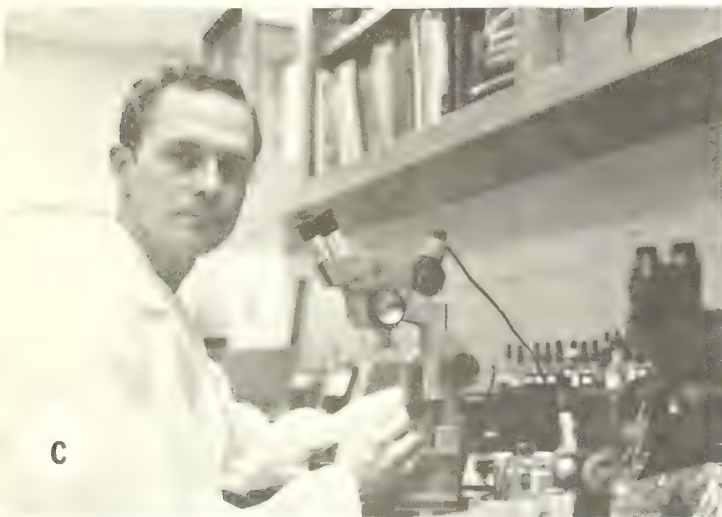
Management—Alpine and Subalpine Ranges—
W. M. Johnson, Project Leader
Dixie R. Smith
Water Yield Improvement—Sagebrush Lands—
H. W. Berndt, Project Leader
R. D. Tabler
B. A. Hutchison



A



B



C



D

A, A. Judson, measuring shear strength of snow, Berthoud Pass, Colorado, 1963.

B, P. O. Currie and F. L. Hammer, injecting radioactive phosphorus into soil to measure lateral spread and depth of roots of native plants, Manitou Experimental Forest, Colorado.

C, J. M. Staley, examining needle cast fungus of conifers.

D, D. C. Markstrom, checking a test panel of laminated decking fabricated from Black Hills ponderosa pine.

E, An experimental solar-heated lumber dryer used in tests at Colorado State University.

F, Soft rime accumulated on three-cup anemometers until electric infrared de-icers were installed on 12,493-foot summit of Mines Peak, Colorado.

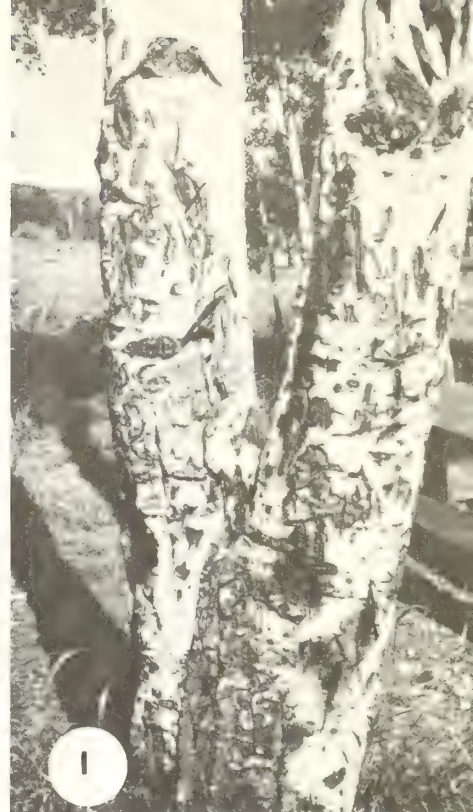
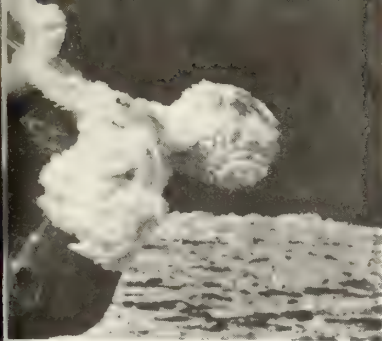
G, High-speed photography helped in study of the spread of dwarf mistletoe. Velocity of seed expulsion averaged 72 to 85 feet per second.

H, Charcoal kiln constructed of native adobe, southern Arizona.

I, Mechanical injuries on aspen trees are prime entrance points for canker diseases. The cankers eventually girdle the tree and cause its death.



E

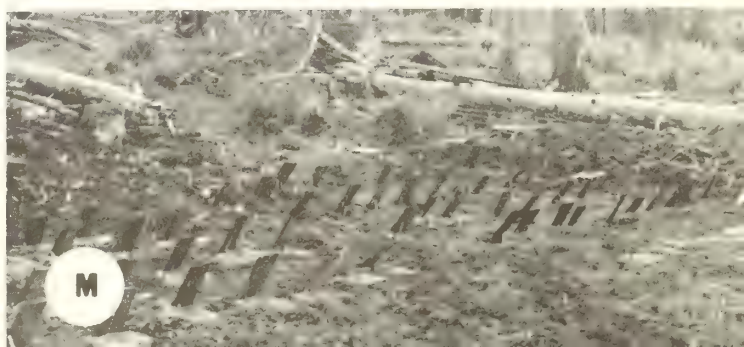


J, Soil and litter wettability influences hydrology on many sites. A drop of water (with tracer added) shows the resistance of Utah juniper litter to wetting, central Arizona.

K, A controlled hot surface fire like this consumes 75 percent of the litter—optimum for increasing water yield.

L, Chemicals in juniper foliage inhibited grass growth beneath the tree.

M, Engelmann spruce and lodgepole pine seedlings, planted at high altitudes, survived better when shaded and mulched. White River Plateau, Colorado, 1957.



Assistant Director Organization to Further Strengthen Research

To further strengthen the emphasis on basic in-depth research needed to guide the increasing use of forest land resources, key research personnel were relieved of administrative duties and returned to project research. M. D. Hoover assumed leadership of the major water-yield improvement and channel stabilization project at Fort Collins and Albuquerque. N. D. Wygant assumed leadership of special forest insect and S. R. Andrews of forest disease research projects at Fort Collins. L. A. Mueller assumed active project work in forest products utilization at Fort Collins.

To make these changes possible, the research of the Station was organized and administered by five assistant directors. R. D. Lloyd transferred to the Station from the Bureau of Land Management, Washington, D. C. He headed up and gave dynamic leadership to Forest Economics, Utilization, and Recreation Research, including the Beaver Creek Evaluation Project. At this same time, the fiscal and accounting, business management, personnel, library, biometry, and publication and information services were placed under the supervision of D. M. Ilch as Assistant Director. H. C. Fletcher returned to the Station from the Washington, D. C. headquarters of the Agricultural Research Service, to become the Assistant Director of Watershed Management Research.

Assistant Director Organization, 1965

Director: Raymond Price

Assistant Directors:

Forest Economics, Utilization, and Recreation Research—R. D. Lloyd

Range Management and Wildlife Habitat Research—E. H. Reid

Timber Management and Forest Protection Research—G. L. Hayes

Watershed Management Research—H. C. Fletcher
Station Management—D. M. Ilch

With this new organization, several new research activities were added to the Station program, some westernwide and some national in scope. These included Westernwide Range Inventory Analysis in 1965 under R. S. Driscoll; National Fire Danger Rating in 1966 under M. E. Schroeder and J. W. Lancaster; Westernwide Avalanche Hazard Rating in 1969 under A. Judson; and the National Range Plant Project and Herbarium in 1970 under F. J. Hermann and C. Feddema.

Study of visitor use of campgrounds showed family units closer together than 100 feet receive least use.

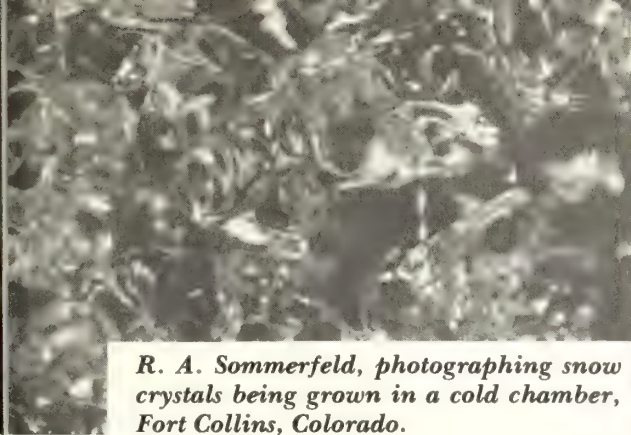
In 1966 the Central States Forest Experiment Station was abolished, and, in the realignment of the research in the Midwest, the shelterbelt research in the northern Plains at Bottineau, North Dakota, formerly under the Lake States Station, was added to the Rocky Mountain Station. This move consolidated all shelterbelt research by the Forest Service at the Rocky Mountain Station. P. E. Slabaugh was the Project Leader at Bottineau and remained so until his retirement in 1973, when R. W. Tinus assumed these responsibilities. R. A. Read continued as Project Leader at Lincoln, Nebraska.

With the increasing pressure for more big-game, the range-wildlife research at Laramie was enlarged to include elk range management in 1967 under A. L. Ward. Forest Insect Research was also broadened in 1967 to include studies of insects of shelterbelts and forest nurseries at Bottineau by M. E. McKnight.

Several key personnel changes were made during this same period as the result of retirements. D. E. Morton replaced D. M. Ilch, as Assistant Director of Station Management in 1967. R. E. Stevens replaced N. D. Wygant as Project Leader of Forest Insect Research in 1968. Stevens came to the Station from the Division of Forest Insect Research, Washington Office. C. M. Berntsen replaced G. L. Hayes as Assistant Director of Timber Management Research in 1969. Berntsen came from the Washington Office Division of Timber Management Research. H. A. Paulsen, Jr. replaced E. H. Reid as Assistant Director of Range and Wildlife Research. Paulsen came from the Washington Office Division of Range and Wildlife Habitat Research.

Other additions to the Station Staff included a full-time Librarian, Mrs. Frances J. Barney (1967) and an Information Officer, R. W. Leonard (1969). Under Mrs. Barney's direction, a working reference library was established at the Fort Collins headquarters, and branch libraries established at each field location. P. B. Johnson, a Utah State forestry graduate, transferred from Region 4, in 1972, to replace Leonard. Johnson has aided materially in increasing the image of the Station and its work.





R. A. Sommerfeld, photographing snow crystals being grown in a cold chamber, Fort Collins, Colorado.

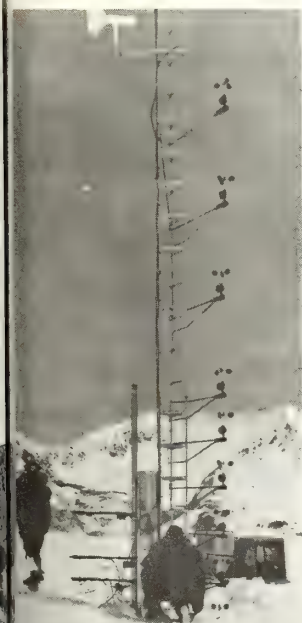


Computerized Management

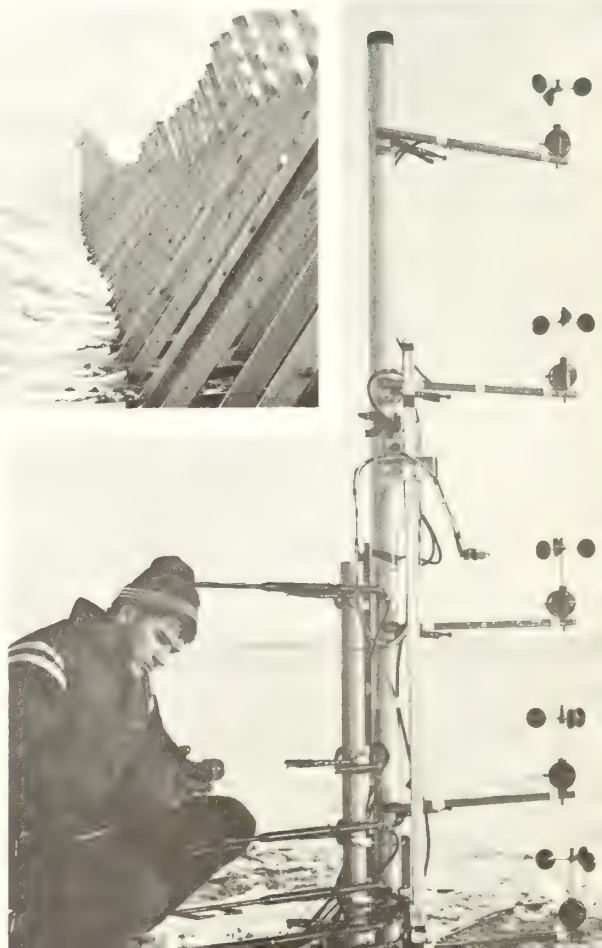
With the development of electronics and computers and the increasing skills in these fields at the Station, marked advancements were made beginning in the late 1960's in design of experiments, computation and analyses of data, and the extension of research data to management and use. Some examples of this development include: models of sublimation of blowing snow for designing snow fence systems (R. A. Schmidt, Jr., and R. D. Tabler); computerized management of ponderosa pine in the Black Hills and, more recently (1975), new guidelines for management and use of ponderosa pine forests of the Colorado

Front Range (C. A. Myers); models for evaluating multiple resource data from Beaver Creek (R. D. Lloyd and H. E. Brown); economic models for evaluating alternative chaparral management practices (P. F. O'Connell); model of air flows in fire danger rating (M. A. Fosberg); models for determining airflow in lodgepole pine stands (J. D. Bergen); model for revising streamflow forecasts (C. F. Leaf and G. E. Brink); prediction of softwood cutting yields by computer (D. C. Markstrom and B. J. Erickson); and the National Fire Danger Rating System (J. E. Deeming, J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder). These improvements and advancements have extended research information and its application to forestry resource problems.

77



R. A. Schmidt, Jr., and R. D. Tabler, developing models of sublimation for blowing snow control. Schmidt (right), calibrating a snow particle counter; Tabler (above), observing snow depth behind an experimental snow fence, near Laramie, Wyoming.





A



B



C

A, M. A. Fosberg, checking recorded data in study of climatic influence on the environment (Colorado Springs Gazette-Telegraph photo by S. Payne; courtesy of Pikes Peak Regional Library).

B, W. J. Greentree, scanning satellite photography with automatic microdensitometer to map wildland resources. Fort Collins, Colorado.

C, O. C. Wallmo, working with trained deer used in forage studies in Colorado.

D, A. L. Ward, releasing telemetered cow elk for habitat study in Wyoming.



D





E, J. W. Riffle, examining culture of diseases affecting shelterbelt trees in the Great Plains. Lincoln, Nebraska.

F, R. W. Tinus, examining 6-month-old Siberian larch seedlings grown in controlled environment greenhouse. Bottineau, North Dakota.

G, R. S. Driscoll, inspecting low-light television camera prior to resource inventory flight. Fort Collins, Colorado.

H, D. R. Patton, checking Abert squirrel trapped as part of wildlife habitat study in Arizona.

I, J. D. Bergen, checking equipment used in studies of air movement in a forest clearing as indicated by smoke drift. Fort Collins, Colorado.



Adapting Research to Environment

With the approach of the seventies, problems of the environment became a national issue. The long-used term "ecology," a byword in professional forestry circles, was "discovered" by the public. Aspiring political leaders became champions of the environment.

It was apparent that wildland resource scientists were guilty of "hiding their light." They had not publicized or glamorized their ecological know-how.

Awakening to this public surge in environmental interest, it seemed in order for Station scientists to describe ongoing research in more readily understandable terms, and to begin more direct environmental research.

One of the first more direct environmental studies in 1970 was determining the effects of properly located barriers of trees and shrubs to reduce highway noise. This research, conducted near Lincoln, Nebraska, was a cooperative study by Professor D. I. Cook, University of Nebraska, College of Engineering, and D. F. Van Haverbeke of the Station.

Groundwork was also begun in 1970 toward the development of a proposed western environmental research institute. In 1971, G. D. Lewis of the Division of Economics, Washington Office, was transferred to the Station to begin environmental economic research. His assignment was to determine what economic information is most important to land use planning, and to evaluate the economic consequences of rapidly growing recreation communities in the forest environment.

After nearly 41 years in forestry research, 30 of which were devoted to directing research in the Southern and Central Rocky Mountain

Regions, Raymond Price retired May 28, 1971. Karl F. Wenger, Chief of Conifer Ecology and Management Research in the Washington Office, became the new Director. Wenger was a forestry graduate of the University of Maine. He received his M.F. and Ph.D. at Duke University. His previous assignments had been at the Southern and Southeastern Stations.

The Eisenhower Consortium for Western Environmental Forestry Research

With the tremendous population growth, in and adjacent to the Rocky Mountains during the 1960's and 1970's, came ever increasing demands for wildland resources and for occupancy of the land itself either on a permanent or temporary basis. Forest Service researchers alone could not possibly uncover all the information needed by land planners and managers to cope with these new impacts. The Eisenhower Consortium for Western Environmental Forestry Research was established September 9, 1971, to pool the talents of Rocky Mountain Station scientists with those of researchers in nine western universities (University of Wyoming, Colorado State University, University of Colorado, Northern Arizona University, Arizona State University, University of Arizona, University of New Mexico, New Mexico State University, and Texas Tech University).

The goals of the Consortium are to (1) increase understanding of the interactions between people and the environment; and (2) develop methods to provide for the needs and wants of increasing permanent and transient populations while maintaining, and enhancing where possible, the attractive features of the environment. Funding comes

D. I. Cook (Professor, University of Nebraska) and D. F. Van Haverbeke, recording effects of environmental plantings on noise abatement, near Lincoln, Nebraska.



from the Forest Service and other organizations. The intent of the Consortium is to provide commissions, planning boards, and agency administrators with facts to help them chart coordinated, environmentally sound open-space planning and development programs for public and private lands.

Through the first 4 years of its existence, Consortium members conducted 88 studies crossing five critical problem areas. Major results from some of these, and other related studies, were summarized at a Consortium-sponsored symposium in Vail, Colorado, in September of 1975. Title for the symposium was **Man, Leisure, and Wildlands: A Complex Interaction**. Land use planners as well as scientists attended the meeting.

To help the Consortium and other research organizations in the West set research priorities, a comprehensive problem analysis was initiated in 1973. Sponsored by the Consortium and the Institute of Ecology,²³ it was funded by the National Science Foundation, the Forest Service, and the Environmental Protection Agency. Some 300 specialists from all disciplines associated with natural resources in the West were mobilized to undertake the problem analysis. The specialists prepared committee reports on mineral and energy resources, recreation uses, water resource and second home uses, human needs and responses, institutional arrangements, and biological resources. This effort was guided by a three-man directorate headed by John M. Neuhold of Utah State University. Assisting were Duncan T. Patten of Arizona State University and David E. Herrick, who represented the Station. The final report, **Problems and Research Priorities in the Rocky Mountain Region**, was released for use in the summer of 1975.

²³The Institute of Ecology (TIE) is a consortium of universities and research institutes in the Western Hemisphere that synthesizes ecological concepts and relates them to public policy. (TIE, 955 L'Enfant Plaza, S.W., Suite 2600, Washington, D. C. 20024.)

Eisenhower Consortium sponsored a symposium at Vail, Colorado, in September 1975, and took participants on a field trip to nearby Maroon Bells.

Additional Environmental Research

With the availability of funds from the Surface Environment and Mining (SEAM) Project—a research, development, and application program to help meet the Nation's energy crisis, and to produce needed minerals in harmony with a quality environment and other natural resource values—several projects were reorganized and new objectives pursued. In 1973 at Albuquerque, the watershed and erosion control and range improvement projects were combined, and research directed toward mine spoil reclamation in the Southwest with E. F. Aldon as leader. Also, at Rapid City the direction of range and wildlife management research was changed to include mine spoil rehabilitation. A. J. Bjugstad from the Division of Forest Environment Research in Washington, became the leader of the multi-functional project at Rapid City. Range research at Laramie was also redirected toward spoils residues.

The Federal Highway Administration made funds available in 1973 in Wyoming to determine the extent to which road construction and traffic affect game animal habitat, population, and movement. This made it possible for A. L. Ward to expand research on elk management and begin work on other big-game species.

Also in 1973, Recreation Research was reopened. B. L. Driver of the University of Michigan came to the Station. The mission of his project includes determining the benefits recreationists accrue from different experiences in different environments, and developing management guides for producing desired user benefits while protecting recreation and other resource values.

With publication of the National Fire Danger Rating System, emphasis in fire-danger-rating



research shifted to application and refinement of the System. W. Lancaster and J. Deeming moved to Boise, Idaho, to work at the Interagency Fire Center.

In 1974, Fire Research was reestablished and broadened. The research was headquartered at Tempe, Arizona. J. Dieterich transferred to the Station from Fire Research in Washington, D. C., and assumed the leadership of the project. The mission of the project is to develop guidelines and technology for protecting human life, property, and natural resources from wildfire, reducing wildfire hazard through improved fuel management, and using fire as a management tool in forest cover types of the Central and Southern Rocky Mountains.

Multifunctional Research Work Units

To further emphasize environmental research, several projects were combined into multifunctional work units.

Two such work units were established in Fort Collins. One, "Multiresource Management of the Central Rocky Mountain Subalpine Coniferous Forests," is led by R. R. Alexander. The mission of this work unit is to obtain further ecological information to help land managers predict the interactions of forest resources in Rocky Mountain subalpine forests. This unit combined the former research projects at Fort Collins in timber management by Alexander and Ronco, watershed management by C. F. Leaf, range management by G. T. Turner, and wildlife management by O. C. Wallmo. The other multifunctional project is "Multiple-Use Management in the Montane and Foothill Zones of the Rocky Mountains," with C. A. Myers as leader. Its project mission is to enable land use planners and managers to predict the interactions of people and natural resources in the Foothill and Montane zones and to incorporate this information into tools planners and managers can use to make management decisions for optimum benefit to people. This project includes the mensuration research by Myers, range management research by P. O. Currie, watershed management research by H. R. Gary, and range biometry research by M. J. Morris.

In Arizona, the research in pine-fir and chaparral was combined in a research project for Land Use Planning and Management with J. R. Thompson, leader. A recent offshoot of this project is the "Thomas Creek Resource Evaluation Study." This is another cooperative undertaking with Region 3. Its objective is to develop the basis for determining the best possible mix of

products and services in alternative land management schemes for the mixed conifer forest type.

In 1974, the new project, Mountain Meteorology, was established in Fort Collins. D. G. Fox, Chief of the Model Development Branch of the Environmental Protection Agency's Meteorology Laboratory at Research Triangle Park, North Carolina, transferred to the Station as Project Leader. This project combines the research by M. A. Fosberg, R. W. Furman, and J. D. Bergen. The research goals are to learn how air currents, temperature, humidity, and precipitation behave in forested mountain regions, and to assess the effects of atmospheric conditions on forest management practices.

Further Reorganization of Director's Staff

In line with the consolidation and reorientation of field projects, the Department of Agriculture approved in 1973 an internal reorganization of the Forest Service experiment stations. In this new organization, D. E. Herrick became Deputy Director of the Station. Herrick came to the Station in 1970 as Assistant Director to replace R. D. Lloyd, who had moved to the Washington office. Other positions in the Director's staff included two Assistant Directors for Continuing Research, V. L. Duvall at Tempe, responsible for research in west Texas, New Mexico, and Arizona; and W. A. Laycock at Fort Collins, responsible for research in North Dakota, South Dakota, Nebraska, Kansas, Wyoming, and Colorado. Laycock transferred from the Intermountain Station and Duvall from the Southern Station. H. C. Fletcher retired. Also included was an Assistant Director for Planning and Application, H. A. Paulsen, Jr.; and an Assistant Director for Research Support Services, D. H. Morton. C. M. Berntsen transferred to the North Central Station as Deputy Director. Later, in 1974, D. H. Morton transferred to the Pacific Northwest Region as Deputy Regional Forester for Administration. D. R. Keefer of the Property Management Branch, Division of Administrative Services in Washington, D. C., replaced Morton as Assistant Director.

After about 4 years as Director of the Station, Wenger retired on April 11, 1975. D. E. Herrick, Deputy Director, was appointed Director. Herrick earned B.S. and M.F. degrees in forest management and utilization from Iowa State University where he also served on the faculty before joining the Forest Service.

Dixie R. Smith was appointed Deputy Director. Smith was in charge of the Wildlife Habitat and Range group of the Forest Environment Research staff, Washington, D. C. He received

his B.S. from Texas Technological College and Ph.D. from the University of Wyoming. He was formerly a project leader at the Station, headquartered at Laramie, Wyoming, 1962-69.

Just before Wenger retired, announcement was made of two new Research Work Units to be added to the Station in 1975. The largest of the Units, Resources Evaluation Techniques, a Research and Development Program, was established in response to the Forest and Rangeland Renewable Resources Planning Act of 1974. The act requires that the Forest Service, with other Federal agencies, provide Congress with a nationwide assessment of renewable resources in 1975, 1979, and every 10 years thereafter. The goal of the Unit is to devise the techniques whereby the Forest Service can achieve rapid, accurate, resource inventories and evaluations. R. S. Driscoll is program manager. This program includes the former projects for Westernwide Range Inventory Analysis (Rocky Mountain Station) and Remote

Sensing (Pacific Southwest Station, Berkeley, California).

The second Unit is National Fuel Inventory and Appraisal. This unit will design ways to (1) inventory amounts and types of fire fuels in the forest; (2) predict the behavior of fire in different fuel types; (3) relate these to the National Fire Danger Rating System; and (4) combine onsite fuel information and current weather to predict fire intensity and spread. S. N. Hirsch has been selected to lead this project, and will transfer from the Pacific Southwest Forest and Range Experiment Station's Forest Fire Laboratory at Riverside, California.

As 1975 drew to a close, the theme of the Eisenhower Consortium sponsored symposium at Vail, Colorado in September: "Man, Leisure, and Wildlands: A Complex Interaction," might well set the course of forestry research in the central and southern Rocky Mountain Regions in the years ahead.

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Fort Collins, Colorado

Project Leaders' Meeting—March 25-27, 1975

(Left to right)

First row (seated on ground): D. R. Carder, F. G. Hawksworth, R. E. Stevens, G. D. Lewis, R. W. Tinus, D. R. Patton, J. W. Lancaster.

Second row (seated): D. R. Keefer, H. A. Paulsen, Jr., D. A. Lingwood (CRUSK), D. E. Herrick, W. C. Morris (CRUSK), M. B. Dickerman (WO), K. F. Wenger, W. J. Lucas (R-2), W. D. Hurst (R-3), R. Lindmark (INT), W. A. Laycock, V. L. Duvall.

Third row (standing): C. A. Myers, A. J. Bjugstad, A. L. Ward, C. Feddema, H. K. Orr, R. S. Boster, D. D. Elser, G. H. Schubert, H. E. Worth, E. F. Aldon, J. L. Kovner.

Fourth row (all remaining standing): G. W. Peterson, M. Martinelli, Jr., J. F. Thilenius, D. F. Van Haverbeke, S. C. Martin, R. S. Driscoll, D. G. Fox, W. P. Clary, S. S. Sackett, J. R. Thompson, B. L. Driver, J. H. Dieterich, R. R. Alexander, R. A. Read, R. H. Hamre, R. D. Tabler, L. L. Manley.

(Absent were P. F. O'Connell and P. B. Johnson. Meeting included all Project Leaders, Section Heads of Research Support Services, and guests and scientists who participated. Station's total full-time staff as of October 1, 1975 was 220 people; 90 were project leaders and scientists, 50 were technicians, 74 were Research Support Services and Clerical, and 6 were on the Director's immediate staff.)





The Distaff Side

The women of the Forest Service research organizations in the Central and Southern Rocky Mountain Regions have been outstanding. These include the wives of the scientists and the women employees.

84 The role of the wives of the scientists in a developing activity such as forestry research, was challenging and often trying. Transfers were frequent, and suitable housing usually was hard to find. In most instances field quarters were primitive and rugged. The men's duty hours had to match research requirements, which made family planning difficult. Moreover, travel schedules and requirements often left the wives at home with the sole responsibility for the families. Sometimes the wives helped their husbands in the field. Take Elinore Martinelli, for example. She was out on the alpine snowfields with Pete taking notes for him. When Lynn came Elinore was grounded, but not for long. Soon she took Lynn piggyback and again was off to the snowfields with Pete!

Thanks to the wives, the families kept close together and met the challenges. An activity that helped the wives at Station headquarters share their challenges and responsibilities was a monthly social which became known as "The Forestry Triangle." This group included the wives and women employees of the Forestry School (Education), of the Roosevelt National Forest and other local resource Administrative Agencies (Administration), and the Station (Research).

Dorothy McArdle, Myrtle Connaughton, and Rose McGinnies took the lead at the former Rocky Mountain Station. Beth Price took the lead at the Southwestern and the new Rocky Mountain Stations. These women played an important role in maintaining friendly associations within the Stations and among the forestry organizations.

The women employees since the beginning of the Stations have been efficient and dedicated, and have relieved the scientists of many chores. It is not possible to name them all here, but the history would not be complete without naming a few. At the Southwestern Station, Marjory P.

Rickle deserves recognition for her efficient service. As Director's secretary, Mrs. Rickle kept an even keel at that Station. At the former Rocky Mountain Station, Eunice Skamser and Maria Garwood must be recognized. Miss Skamser, chief clerk in 1935, helped in several capacities. Mrs. Garwood, who also came in 1935, served as secretary to four Directors, including the Director of the new Rocky Mountain Station, until her retirement in 1968. She was a most efficient and dedicated employee, adding much to the Station's accomplishments.

In 1967, as part of the expansion program, a working reference library was added to the Station, with Frances J. Barney as librarian. Mrs. Barney holds B.S. and M.S. degrees in botany, and came to the Forest Service from the library at Colorado State University. She served as a research assistant in plant pathology at Connecticut Agricultural Experiment Station and as a librarian at Duke University. Her intimate knowledge of the natural resources and library science, as well as her devotion to her responsibilities make her a valuable asset to the Station's scientific efforts.

Two women who advanced from clerical to professional positions must be recognized—Geraldine Peterson and Mona F. Nickerson. Mrs. Peterson, who earned her B.S. in mathematics at the University of Arizona, and authored several publications, was a statistical clerk at the Southwestern Station. She transferred to the new Rocky Mountain Station when the Stations were combined, where she helped materially in computation of research data. She retired in 1965. Mrs. Nickerson earned her B.S. degree in economics and B.A. in technical journalism at Colorado State University. She served in stenographic and clerical duties with the former Rocky Mountain Station. Later, she became a technical publications editor, and is in the Publications Branch of the new Rocky Mountain Station. Mrs. Nickerson completed the editorial services for this history. Her interest and knowledge of the Station has been most helpful in searching for illustrations and records.



Cooperation With Other Agencies

Cooperation with other agencies has characterized the research of the Forest Service throughout its history. Many of the accomplishments obtained over the years at the Southwestern and Rocky Mountain Stations are, in part, the result of cooperative effort. This effort included counsel and advice; furnishing of quarters including office, laboratory, and library facilities; financial contributions; publication of findings; and participation in the conduct of research. The cooperators were many, including universities and colleges, associations, industry, State and other Federal agencies, and private individuals.

Universities and Colleges

The Station's longest cooperative relationship of record is that with the University of Arizona. This relationship began with the establishment of the Santa Rita Range Reserve in 1903. It has continued over the years and is still active.

Cooperation with New Mexico State University (then New Mexico A&M) began with the establishment of the Jornada Range Reserve in 1912. The Jornada was transferred to the Agricultural Research Service in 1953, but active cooperation continues with New Mexico State University and the University of New Mexico.

Another long and continuous cooperation is with Colorado State University (formerly Colorado A&M). This cooperation began formally when the former Rocky Mountain Station was established in 1935. It has waxed strong and enlarged over the years. The close working relations with the College of Forestry and Natural Resources has been and is especially helpful. Colorado A&M College and Colorado College (at Colorado Springs) also cooperated in some of the early work at the old Fremont Experiment Station near Manitou, Colorado.

Other universities and colleges that have been and are cooperators in various aspects of research, in more or less chronological order,

include the following: University of Wyoming, University of Nebraska, Arizona State University, Northern Arizona University, South Dakota School of Mines and Technology, North Dakota School of Forestry (which entered into cooperation earlier with the former Lake States Experiment Station), University of Colorado, Western State College at Gunnison, Colorado, University of Utah, and Texas Technological University.

Association, Industry, and Private Cooperators

Formal cooperation with the Salt River Water Users Association began in 1953 with the logging of the Workman Creek Experimental Watersheds—the beginning of the Arizona Watershed Program. The cooperation is continuing.

Formal cooperation with other associations includes the Arizona Goat and Mohair Association, in a study of goat range in central Arizona; the Crow Valley Livestock Association in cattle grazing at the Central Plains Experimental Range; The Black Mesa Cattlegrowers in cattle grazing at the Black Mesa pastures; and the Colorado Cattlegrowers in pocket gopher studies. Koppers Company of Denver cooperated in the timber harvesting at Fraser. Duke City Lumber Company cooperated in the overlaid lumber manufacturing study at Albuquerque.

Formal cooperation with private individuals includes the operating stockmen at the Santa Rita, Jornada, Manitou, and Big Horn experimental areas.

State and Other Federal Agencies

State agencies that have cooperated in the research are many. Chief among these are the Fish and Game Departments of the States of Arizona, Colorado, New Mexico, South Dakota, and Wyoming. The State Engineer in New Mexico actively participated in streamflow measure-

ments. The State and Extension Foresters of the Rocky Mountain States, especially the States of Colorado, Wyoming, North and South Dakota, Kansas, Nebraska, and New Mexico gave strong support and participated in several surveys and studies. The Wyoming Highway Department sponsored research on design of fence systems to control blowing snow.

The Arizona Water Resources Committee, a State-sponsored citizens' group supporting the Arizona Watershed Program, has been and continues to be most helpful. The support of this committee made it possible to conduct the research on which the Arizona Watershed Program is based.

Of the Federal agencies, the cooperation—both formal and otherwise—of Region 2 and Region 3 of the Forest Service is immeasurable. Many research accomplishments would have been impossible without their support and encouragement.

Next to the two Forest Service Regions, the first and longest continuing cooperation was that of the former Forest Pathology Division of the Bureau of Plant Industry. In accordance with the agreement of March 21, 1910, between the Forest Service and this Bureau, W. H. Long, forest pathologist, assumed his duties in the Southwest in 1911 and established his headquarters in Albuquerque, New Mexico, in 1913. Dr. Long worked closely with G. A. Pearson, and was considered a member of the research team until his retirement in 1937. L. S. Gill followed Dr. Long, and he and his staff continued close cooperation with the Station. They became an integral part of the Station in 1953, and Gill became Chief of Forest Disease Research at the Station.

Although a forest pathologist was never assigned to Region 2 of the Forest Service under the original Facilitating Agreement, Long and other pathologists from Washington, D. C. were frequent visitors as consultants. From 1914 until his death in 1925, Ellsworth Bethel served as a forest pathologist with headquarters in Denver. As a specialist on western rusts, his main assignment was to study native rusts that might be confused with the introduced white pine blister

rust. Beginning in 1951, R. W. Davidson was stationed in Fort Collins in cooperation with Colorado A&M College.

Forest entomology investigations, under the old Bureau of Entomology and Plant Quarantine, began with an outbreak of the mountain pine beetle in the Black Hills of South Dakota about 1900. From 1900 to 1909, A. D. Hopkins and associates studied several species of tree-killing beetles in the Rocky Mountains. Also, from 1910 to 1935, a limited amount of research on forest insects was done by entomologists visiting from the Forest Insect Laboratory at Berkeley, California. A Forest Insect Laboratory was established at Denver, Colorado, in January 1935 with J. A. Beal in charge. This new Forest Insect Laboratory moved to Fort Collins in September 1935 in cooperation with Colorado A&M. This move also marked the formal cooperation with the former Rocky Mountain Station which continued until 1954 when the laboratory became part of the new Rocky Mountain Station. N. D. Wygant, then Laboratory Leader, became Chief of Forest Insect Research at the Station.

The Fish and Wildlife Service (formerly Biological Survey), Department of the Interior, under the McSweeney-McNary Act, assigned a biologist to each western experiment station to advise and conduct research pertaining to wildlife. These assignments began soon after the passage of the Act, and have been continued since that time by several competent biologists.

The Bureau of Land Management, Bureau of Indian Affairs, Bureau of Reclamation, and National Park Service of the Department of the Interior cooperated in studies from time to time. The Bureau of Land Management supported the grazing studies in northern New Mexico and in Wyoming, and the Indian Service cooperated in surveys and studies in the use of fire in Arizona. The Bureau of Reclamation cooperated in watershed activities in Colorado. The Park Service cooperated in forest disease and forest insect research. All of these agencies were major clients of Forest Service research. Dr. Frederick V. Coville of the former Bureau of Plant Industry and his coworkers in the Smithsonian Institution aided in plant identification.





Some Research Highlights and Accomplishments

It is not possible to cover here the vast amount of research information obtained over the years by the Forest Service in the central and southern Rocky Mountain Regions. Most of this information has been presented in numerous publications, including scientific journals, U.S. Department of Agriculture publications, serial publications by the Station, trade journals, and other media. These publications contain references to related and supporting studies. Also, the Station recently made available a complete list of publications, alphabetically by author, for the period 1953-73.²⁴

The Station has released a series of "Status of Knowledge" publications in timber, watershed, and range management. These reports are designed to provide land managers and administrators with concise overviews of specific resources in the Station territory, with summaries of major research results (extending back to the turn of the century in some cases), and ideas on how managers might apply the results to help solve problems. They also outline research needed to fill knowledge gaps in the respective fields. The report series include timber management for the five major timber types in the Station territory;²⁵ watershed management in five vegetation types in the Southwest,²⁶ and five in the Black Hills and central Rockies;²⁷ and range management for seven rangeland types in the central Rockies and Southwest.²⁸ These "Status of Knowledge" reports are proving very useful to managers and are in great demand. Hence, information about studies undertaken and results obtained over the years may be found in these papers and from the bibliographies contained therein.

It is highly appropriate, however, to mention some of the pioneering efforts and significant contributions made to forestry research by Forest Service scientists who have worked in the central and southern Rocky Mountain Regions. For this purpose, these accomplishments are grouped into four broad areas of research:

1. Ecology and management of major timber species in the central and southern Rockies, including the biology and ecology of damaging forest insects and diseases, and forest fires.
2. Range ecology, range rehabilitation, and management, including range livestock production and wildlife habitat.
3. Watershed management, including erosion control and water-yield improvement.
4. Multiple use evaluation of forest land management.

Ecology and Management of Timber Species, Including Biology and Ecology of Insects and Diseases, and Forest Fires

As stated previously, little information existed concerning the timber species, their requirements, and proper use at the time the Forest Reserves were established. Hence, G. A. Pearson and Carlos G. Bates, the two pioneer silviculturists assigned to the central and southern Rocky Mountain Regions, began the timber management research and left several research reports as monuments to their work.

In the Southwest, Pearson's reports of natural reproduction of western yellow pine, forest types as determined by climate and soil, improvement selection cutting in ponderosa pine, and his culminating monograph—"Management of ponderosa pine in the Southwest," are major contributions. These have been of great value to forest land managers in the Southwest and neighboring regions.

Hermann Krauch, who also worked during the early period of timber management research in the Southwest, contributed several research papers on individual tree studies of ponderosa

²⁴USDA Forest Service General Technical Report RM-6, 96 p. 1974.

²⁵USDA Forest Service Research Papers RM-120, 121, 122, 123, 124.

²⁶USDA Forest Service Research Papers RM-117, 126, 127, 128, 129, 130.

²⁷USDA Forest Service Research Papers RM-137, 138, 139, 140, 141, 142.

²⁸USDA Forest Service Research Papers RM-154, 155, 156, 157, 158, 159, 160, 161.

pine. He also developed the management requirements of Douglas-fir timberland in the Southwest.

B. R. Lexen was associated with Pearson and Krauch during the early part of his Forest Service career. He introduced statistical computation and analyses to the research, and among his findings was the determination of the factors influencing the yield and mortality of ponderosa pine in the Southwest.

C. A. Myers extended Pearson's work, and made available information regarding converting virgin southwestern ponderosa pine to managed stands.

G. H. Schubert (1971) reported the growth response of even-aged ponderosa pine related to stand density levels. In 1974, Schubert completed an up-to-date review of the silviculture of ponderosa pine. J. R. Jones (1974) reviewed the silviculture of southwestern mixed conifers and aspen. These accomplishments have materially added to forest land management.

In the central Rockies, Bates' work on growth requirements of conifers, seed production and seed source, reforestation, and forest type as determined by climate and soil, provided understanding and guidance to forest land managers generally. Bates encouraged the establishment of growth measurement plots throughout the National Forests of the central Rocky Mountains. The periodic measurements of these plots over the years have furnished much worthwhile information. R. R. Alexander has drawn on these and other forest stand measurements and added much useful information for forest land managers in the central Rockies, including the silvical characteristics of Engelmann spruce and subalpine fir. Alexander also reviewed the silviculture of central and southern Rocky Mountain forests. Alexander's publications on partial cutting of old-growth lodgepole pine and spruce-fir forests are especially helpful in the management and use of these forests.

F. Ronco's work on spruce seedling physiology and requirements for artificial regeneration has provided the basis for regeneration of the extensive insect-killed spruce stands in Colorado and neighboring regions.

C. E. Boldt and J. L. Van Deusen reviewed the silviculture of ponderosa pine in the Black Hills, making available up-to-date information for use in this highly developed area.

Drawing on the above research findings and other forest measurements, C. A. Myers completed an outstanding piece of research on simulating the management of even-aged timber stands (1973). In 1974, Myers extended his research to multipurpose silviculture in ponderosa pine stands of the Front Range in Colorado.

Myers' accomplishments have provided forest land managers and others with the information and techniques for evaluating and appraising timber management practices in advance of operation, and thereby materially advanced forest land management planning.

In Plains forestry, R. A. Read completed an evaluation of the Great Plains Shelterbelts. On the basis of this evaluation, he established and has lead shelterbelt research in the Central Plains. Recently, Read, D. F. Van Haverbeke, and J. A. Sprackling completed provenance and genetic papers on several tree species for planting in the Central Plains. G. W. Peterson began forest disease research in the Central Plains and in a series of papers has made available information and guidance on diseases of forest nurseries and shelterbelts. R. W. Tinus, through his research of containerized seedlings at Bottineau, North Dakota, has provided private and public forestry organizations with useful information and techniques for more efficient and successful forest plantings for the northern Plains.

In Forest Diseases Research, L. S. Gill completed a taxonomic revision of the dwarf mistletoes. Gill also extended W. K. Long's work on both dwarf mistletoe and red rot. F. G. Hawksworth further extended dwarf mistletoe research throughout the central and southern Rocky Mountain Regions and into Mexico, and developed application of his findings to forest land management. Through his prodigious research, Hawksworth has become the recognized authority on dwarf mistletoes. S. R. Andrews concentrated on red rot of ponderosa pine, and summarized his and Long's research in a monographic treatment of this important decay. T. E. Hinds and R. W. Davidson made fundamental contributions in studies of blue stain fungi and canker diseases of aspen, while R. S. Peterson and J. M. Staley did much needed research in their respective fields of rusts and foliage diseases of conifers.

In Forest Fire Research, the work of J. E. Deeming, J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder in developing the National Fire-Danger Rating System is important nationwide. This system is being used throughout the Forest Service and by other Federal and State agencies. A. W. Lindenmuth's research in fire-danger rating and burning characteristics of Arizona chaparral were helpful contributions.



Range Ecology and Range Rehabilitation and Management, Including Range Livestock Production

Management of range livestock grazing was a new experience when the Forest Reserves were established. There were no guidelines. Forest officers had to start from scratch. Damage to the forests from grazing was evident, so this problem drew first attention. Thus it was that R. R. Hill determined and characterized the effects of grazing on western yellow pine reproduction in the National Forests of Arizona and New Mexico. Pearson also noted this problem in his writings. C. K. Cooperrider described the recovery of ponderosa pine reproduction following injury to young annual growth.

Drought and its effects on livestock, especially in the Southwest, was another early problem. Hence, C. L. Forsling and J. T. Jardine outlined measures for range and cattle management during drought. Too many critters and continuous unrestricted grazing greatly accentuated the effects of drought. W. R. Chapline prepared management guides for goat range management on the National Forests. M. W. Talbot's "Indicators of Southwestern Range Conditions" have been widely used by private and public range and range-watershed managers.

Another early need was to determine the range forage constituents, their grazing value and growth habits, and how their presence or absence might indicate range conditions. Ecological findings and descriptions in the central Rockies, as documented by D. F. Costello and H. E. Schwan, are noteworthy. R. S. Campbell determined the plant succession and grazing capacity on clay soils in southern New Mexico. W. G. McGinnies, K. W. Parker, and G. E. Glendening described the ecology of southwestern ranges. Parker developed a scorecard of range conditions. He also developed the three-step method of measuring range condition and trend on National Forest rangelands, which was used nationwide in evaluating range conditions.

Noxious and poisonous plants were increasing problems on the range. On southwestern ranges, increase of mesquite was especially acute. Parker, S. C. Martin, Glendening, H. A. Paulsen, Jr., D. R. Cable, and H. G. Reynolds characterized this problem, and worked out measures for control and management. Parker also developed measures to control burroweed. On the Central Plains, Costello developed methods to control prickly-pear, while C. W. Doran and J. T. Cassady developed methods of management for sheep on western Colorado rangelands infested with orange sneezeweed.

General depletion of rangelands called for concentrated efforts of Forest Service range ecologists to bring about range rehabilitation. Reseeding studies were intensified. In the Southwest, the research of J. T. Cassady, G. E. Glendening, F. Lavin, H. G. Reynolds, J. O. Bridges, and H. W. Springfield made information available for extensive successful range forage improvement. H. B. Pingrey and J. R. Gray of New Mexico State University with E. J. Dortignac and H. W. Springfield of the Station reported on cattle gains and the economics of lambing on range areas in northern New Mexico seeded to crested wheatgrass. In the central Rockies, W. M. Johnson, C. W. Doran, J. T. Cassady, and A. C. Hull developed range reseeding practices for successful range improvement.

As to range and range livestock management, much progress has been made. In the Southwest, E. W. Nelson (1934) and later H. A. Paulsen, Jr. and F. N. Ares (1962) outlined grazing values and management practices for black grama and tobosa grasslands and associated shrub ranges. M. J. Culley determined the economics of the cattle business on semidesert ranges. S. C. Martin and D. R. Cable worked out the grazing values, growth requirements, and use of mixed-grass ranges. J. F. Arnold, D. A. Jameson, and E. H. Reid described the pinyon-juniper type and outlined the effects of grazing, fire, and tree control in this range type.

In the central Rockies, D. F. Costello and G. T. Turner developed the basis for judging range condition and utilization, and G. E. Klipple and Costello reported the vegetation and cattle responses to intensities of grazing on Plains short-grass ranges. W. M. Johnson reported the effects of grazing intensity upon vegetation and cattle gains on ponderosa pine-bunchgrass ranges. Johnson also participated in developing systems of grazing on mountain ranges in Wyoming.

In forest wildlife management, the work of H. G. Reynolds in the Southwest is outstanding. In a series of research papers, Reynolds determined wildlife habitat use and developed ways of habitat management and maintenance in forest wildlife management. O. C. Wallmo's research on deer winter ranges in Colorado and D. R. Dietz's research in deer habitat in the Black Hills are noteworthy.



Watershed Management, Including Erosion Control and Water-Yield Improvement

Watershed management also was a new undertaking at the time the Forest Reserves were created. Hence, the work of Bates and Henry at Wagon Wheel Gap, Colorado, is a benchmark in watershed management research. Here, runoff and water yields under forest practices were first measured; it was the beginning from which many other watershed studies developed. In the Southwest, C. K. Cooperrider developed erosion control methods and watershed management practices used in management of watersheds.

The timber-harvesting-water-production study at the Fraser Experimental Forest in Colorado is a classic in forest-watershed management research. The results have had widespread use on public watershed lands westernwide. Several scientists were involved in the study, including C. A. Connaughton, H. G. Wilm, B. R. Lexen, E. G. Dunford, B. C. Goodell, and L. D. Love. Love and W. M. Johnson also determined erosion and water yield information under various amounts of plant cover and intensities of grazing in the ponderosa pine zone, Manitou Experimental Forest, Colorado.

Much information came from the watershed investigations at the Sierra Ancha Experimental Watersheds in central Arizona. Here, water use by plants, erodability of soils, and plant-soil relationships have been used in developing land use practices on Southwestern watersheds. Those involved include Cooperrider, B. A. Hendricks, W. P. Martin, H. C. Fletcher, and L. R. Rich.

Development in watershed management research in later years was spearheaded by M. D. Hoover. Under Hoover's guidance, the research was directed toward determining and isolating the basic factors involved in water-yield and erosion-control processes. To do this, satellite experimental areas were established from the Fraser and Sierra Ancha experimental watersheds. To man these satellites, Hoover trained a number of younger scientists who have produced much helpful information. Among the contributing scientists in this enlarged program were B. C. Goodell, H. E. Brown, L. R. Rich, A. R. Hibbert, J. R. Thompson, P. A. Ingebo, R. D. Tabler, H. K. Orr, D. L. Sturges, J. P. Bergen, H. L. Gary, C. F. Leaf, R. W. Swanson, and B. H. Heede. J. S. Horton conducted studies pertaining to management of stream-bottom vegetation. His phreatophyte research, especially with tamarisk (saltcedar), has materially aided in the control of this water-using plant in the Southwest.

An important segment of the water-yield improvement research is that pertaining to alpine snowfields headed by M. Martinelli. This is the main snow research project by the Forest Service, and much useful information has been and is being developed that emphasizes the value of high-elevation snowfields and how to develop and manage them. Associated with Martinelli are R. A. Schmidt, R. A. Sommerfeld, and A. Judson. H. Frutiger, of the Swiss Federal Institute for Snow and Avalanche Research, was an early consultant in avalanche control. Frutiger described the avalanche starting zone, and prepared guidelines for the planning and design of permanent supporting structures. Judson is developing snow avalanche forecasting. Tabler has made outstanding application of the control of drifting snow to highway protection in Wyoming.

Multiple Use Evaluation of Forest Land Management

The marked accomplishments in timber, range, and watershed management research in the central and southern Rocky Mountain Regions set the stage and made it possible to apply and evaluate watershed management practices on an operational basis. This new approach had not been attempted elsewhere. It took courage, faith, and a good deal of money to do it. Thanks to the interest and support of the people in Arizona concerned with water-yield improvement, and the desire of the Forest Service to improve the use and management of the National Forests, the task was undertaken.

The main essentials of this unique forest land management evaluation project and the people involved have already been covered. This Beaver Creek Watershed Evaluation Project, headquartered at Flagstaff, Arizona, together with the other associated water-yield improvement and evaluation projects in Arizona, are major accomplishments. If properly pursued to an effective conclusion, the research should continue to contribute to the future of the forest land management in the Rocky Mountain empire.

The present research program of the Station, largely organized on an environmental basis, can best be evaluated in future years.



Personnel

Following is a list of scientists, technicians, administrators, and support service leaders who have served at the Southwestern Station, the former Rocky Mountain Station, and the combined Rocky Mountain Station. Also listed are some early forest and range examiners who served

in Regions 2 and 3. As personnel records are fragmented, some people may have been missed.

Many other employees, including secretaries and other supporting personnel, have contributed to the research program. Unfortunately, records are not complete, making it impossible to include these people.

Adair, Clarence D.*
 Aldon, Earl F.*
 Aldrich, Robert C.*
 Alexander, Robert R.*
 Allen, D. Neil*
 Anderson, Patricia A.*
 Andrews, Stuart R.,
Division Chief,
combined RM Station
 Ares, Fred N.
 Arnold, Joseph F.
 Asmussen, L. E.
 Avery, C. C.
 Bailey, Wilmer F.
 Baker, Malchus B.*
 Barger, R. L.
 Barker, D. J.
 Barney, Frances J.*
 Barnhart, Michael R.*
 Bates, Carlos G.,
Director, Fremont Station
 Beagle, Lawrence D.*
 Beardsley, Wendell G.
 Becker, Maxwell E.
 Benedict, Harris M.
 Bennett, R. K.
 Bergen, James D.*
 Bergstrom, Duane E.
 Berndt, Herbert W.
 Berntsen, Carl M.,
Assistant Director,
combined RM Station
 Bird, Kenneth G.*
 Bjugstad, Ardell J.*
 Blackwell, G. A., Jr.
 Blair, Byron O.
 Bliss, E. Shirley
 Bohning, John W.
 Boldt, Charles E.*
 Bomberger, E. H.
 Bongberg, J. W.
 Boster, Ronald S.*
 Boyd, Raymond J.
 Bradfield, Dewell E.

Bradley, John R.*
 Bridges, Joseph O.
 Brink, Glen E.*
 Brinkman, Kenneth A.
 Brown, Gary R.*
 Brown, Harry E.
 Brown, Thomas C.*
 Buell, Jesse H.,
Division Chief,
combined RM Station
 Burke, Hubert D.
 Cable, Dwight R.*
 Campbell, C. J.
 Campbell, R. S.,
Director,
Jornada Range Reserve
 Campbell, Ralph E.*
 Canfield, Roy H.
 Carder, D. Ross*
 Carpenter, David C.*
 Casner, Wilson B.*
 Cassady, John T.
 Cassidy, Hugh O.
 Cavin, William C.
 Chadwick, H. W.
 Chamberlain, Valden*
 Champagne, Norman E., Jr.*
 Chansler, John F.
 Chapline, W. R.,
Chief, Division of Range
Research, Washington Office
 Clary, Warren P.*
 Collet, M. H.
 Coltharp, G. B.
 Connaughton, C. A.,
Division Chief and Director,
former RM Station
 Conway, Errett M.
 Cooperrider, C. K.,
Division Chief, SW Station
 Costello, David F.,
Division Chief,
former RM Station
 Crafts, Edward C.

Cribbs, William J.
 Culley, Matt J.
 Cunningham, Charles R., Sr.*
 Cunningham, R. A.
 Curnow, R. D.
 Currie, Pat O.*
 Curtis, Willie R.
 Dalton, Adrian E.
 Dana, Robert W.*
 Daniels, John P.
 Davidson, Ross W.
 Davidson, Walter H.
 Davis, Edwin A.*
 Davis, James R.*
 Dawson, David H.
 Decker, John P.
 Deeming, John E.
 Dibbern, John C.
 Diebold, C. H.
 Dieterich, John H.*
 Dietz, Donald R.
 Dix, Mary E.*
 Donnelly, Dennis M.*
 Doran, Clyde W.
 Dortignac, Edward J.
 Douglas, L. H.,
Chief, Office of Grazing Studies,
R-2
 Driscoll, Richard S.*
 Driver, Beverly L.*
 Dunford, E. G.
 Duvall, Vinson L.*
Assistant Director,
combined RM Station
 Edminster, Carlton B.*
 Elser, Duane D.
 Embry, R. S., Jr.
 Erickson, Bernard J.*
 Erickson, Robert B.
 Erwin, Eldon V.*
 Eslyn, Wallace E.
 Evans, Keith E.
 Fate, Dwight L.
 Feddema, Charles*

*With the combined Station at the close of 1975.

Ffolliott, Peter F.
 Fleming, C. E.,
Director,
Jornada and Santa Rita
 Fletcher, Herbert C.,
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Assistant Director,
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 Forsling, C. L.,
Director, Jornada
 Fosberg, Michael A.*
 Fox, Douglas G.*
 Francis, Richard E.*
 Frank, Ernest C.*
 Freeland, F. Dean, Jr.
 Furman, R. William, II*
 Gaines, Edward M.,
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 Garcia, George*
 Garrett, E. Chester*
 Gary, Howard L.*
 Geiger, M. L.
 Germain, Charles J.
 Gibbons, Robert D.
 Gill, Lake S.,
Division Chief,
combined RM Station
 Ginter, P. L.
 Glendening, George E.
 Godsey, Gary L.
 Goodell, B. C.
 Goodwin, Gregory A.*
 Gottfried, Gerald J.*
 Green, Win
 Greentree, Wallace J.*
 Haeffner, Arden D.
 Hahn, Temple T.
 Hammer, F. L.
 Hamre, Robert H.*
 Hansen, Edward A.
 Hansen, T. W.
 Hanson, Roy
 Harris, R. W.
 Hathaway, C. R.
 Hawksworth, Frank G.*
 Hayes, G. Lloyd,
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 Haynes, Richard A.*
 Heede, Burchard H.*
 Heidmann, Leroy J.*
 Heidt, Jack D.
 Hendricks, Barnard A.
 Herman, Francis R.
 Hermann, Fred J.

Hensel, R. L.,
Director, Santa Rita
 Herrick, David E.,*
Assistant Director, Deputy
Director, and Director,
combined RM Station
 Hiatt, Harvey A.*
 Hibbert, Aldon R.*
 Hickey, W. C., Jr.
 Hill, L. K.
 Hill, R. R.,
Chief, Office of Grazing
Studies, R-3
 Hinds, T. E.*
 Holbo, H. Richard
 Holub, Ernest W.*
 Hoover, Marvin D.,
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 Hornibrook, E. M.
 Horton, J. S.
 Hovland, Teddy L.*
 Hudson, R. K.
 Hughes, Jay M.
 Hull, Alvin C., Jr.
 Hull, Herbert M.
 Hurd, R. M.
 Hurtt, L. C.,
Director, Jornada
 Hutchison, Boyd A.
 Ilch, D. M.,
Assistant Director,
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 Jairell, Robert L.*
 Jameson, Donald A.
 Jennings, Daniel T.*
 Johnson, Jerry
 Johnson, Kendall L.
 Johnson, Philip B.*
 Johnson, Wallace M.
 Jones, John R.*
 Judson, Arthur*
 Keefer, Donald R.,*
Assistant Director,
combined RM Station
 Keith, James O.
 Kerbs, Roger R.*
 King, Rudy M.*
 Kissinger, Neland A., Jr.
 Klipple, Graydon E.
 Knight, Fred B.
 Knipe, Oren D.*
 Knott, F. William*
 Koshi, Paul
 Kotok, Edward S.


Kovner, Jacob L.*
 Krauch, Hermann
 Krein, Benjamin J.*
 Kruse, William H.*
 Kuhl, Michael J.*
 LaBau, Vernon J.*
 Lancaster, James W.*
 Landgraf, Amel E., Jr.
 Landt, Eugene F.
 Larson, Frederic R.*
 Larson, Melvin L.
 Lavin, Fred
 Laycock, William A.,*
Assistant Director,
combined RM Station
 Layman, Robert H.*
 Lea, Alfred L.
 Leaf, Charles F.
 Lee, Chester,
Region 2
 Lee, Richard
 Leonard, Roger W.
 Lewis, Gordon D.*
 Lexen, Bert R.,
Division Chief,
former RM Station
 Lightle, Paul C.
 Lindenmuth, Anson W., Jr.
 Little, Elbert L., Jr.
 Lloyd, Grenville B., Jr.
 Lloyd, R. Duane,
Assistant Director,
combined RM Station
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Appendix

EXPERIMENTAL AREAS

Responding to the wise counsel and instruction of Earle H. Clapp (appointed in 1915 as Assistant Chief of the Forest Service in charge of Forest Research), many areas within the National Forests were set aside for possible use for research. Clapp asked that suitable areas be designated and set aside within each major forest type. These instructions were closely followed in the central and southern Rocky Mountain Regions, and many areas so designated. Some have and are being used for research purposes; some are still unused;

and some have been abandoned. As the research required, other areas have been added. Some have received official research area designation (Experimental Forest, Range, or Watershed), while others have not.

The major experimental areas within the territory of the Rocky Mountain Forest and Range Experiment Station at the close of 1975 are listed in chronological order of establishment. An alphabetical list, with a characterization of each area, is also included.

Experimental Areas (in chronological order)

A. Areas designated as Experimental Forests or Ranges

- | | |
|---|---------------------------------|
| 1903—Santa Rita (Arizona) | 1936—Long Valley (Arizona) |
| 1908—Fort Valley (Arizona) | 1937—Central Plains (Colorado) |
| 1909—Fremont (Colorado) | 1937—Fraser (Colorado) |
| 1912—Jornada (New Mexico) | 1938—Manitou (Colorado) |
| 1925—Cloudcroft (New Mexico) | 1938—Sierra Ancha (Arizona) |
| 1931—Denbigh (North Dakota) | 1954—Black Mesa (Colorado) |
| 1932—Mount Graham (Arizona) | 1961—Black Hills (South Dakota) |
| 1932—Parker Creek (Arizona; see Sierra Ancha) | 1968—Redfeather (Colorado) |

B. Areas used for experimental purposes under cooperative agreement, or other arrangement

- | | |
|------------------------------------|--|
| 1909—Wagon Wheel Gap (Colorado) | 1959—Burgess (Wyoming) |
| 1948—Crawford Nursery (Colorado) | 1960—Pole Mountain (Wyoming) |
| 1949—Beaver Rim (Wyoming) | 1961—Fort Bayard (New Mexico) |
| 1950—Cibolla Mesa (New Mexico) | 1961—Sturgis (South Dakota) |
| 1952—No Agua (New Mexico) | 1961—Tonto Springs (Arizona) |
| 1952—San Luis (New Mexico) | 1962—Wild Bill (Arizona) |
| 1953—Badger Wash (Colorado) | 1963—Halsey (Nebraska) |
| 1956—Castle Creek (Arizona) | 1963—Willow-Thomas Creeks (Arizona) |
| 1956—Three-Bar (Arizona) | 1963—Carter Mountain (Wyoming) |
| 1956—Tank Canyon (New Mexico) | 1964—Seven Springs (Arizona) |
| 1957—Beaver Creek (Arizona) | 1967—Stratton (Wyoming) |
| 1958—Mingus Mountain (Arizona) | 1968—Hastings (Nebraska) |
| 1958—White Spar (Arizona) | 1968—Northwest Agriculture Laboratory (Nebraska) |
| 1958—Dubois (Wyoming) | 1970—Mead University Field Laboratory (Nebraska) |
| 1959—Horning State Farm (Nebraska) | 1970—Interstate Highway 80 (Wyoming) |

Experimental Areas (alphabetically by State)

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
A. Areas designated as Experimental Forests or Ranges				
ARIZONA				
FORT VALLEY 1908—Initiated experimental work. 1931—Established as an experimental forest, January 21 1975—Active	Coconino County, Coconino NF	Ponderosa pine	Timber management	Total—4,630 acres; all Federal
LONG VALLEY 1936—Established as an experimental forest, March 31 1975—Active	Coconino County, Coconino NF	Ponderosa pine	Timber management	Total—1,265 acres; Federal, 1,250; Private, 15
MOUNT GRAHAM 1932—Established as an experimental forest, March 23 1967—Disestablished	Graham County, Coronado NF	Mixed conifer	Timber and recreation management	Total—3,920 acres; all Federal
SANTA RITA 1903—Established as a range reserve by Bureau of Plant Industry 1915—Transferred to Forest Service 1975—Active	Pima County, Coronado NF	Semidesert grass-shrub	Range management	Total—53,159 acres; Federal, 51,795; Private, 1,364
SIERRA ANCHA 1932—Established as Parker Creek Erosion-Streamflow Station May 18 1938—Enlarged to Sierra Ancha Experimental Watersheds, April 6 1975—Active	Gila County, Tonto NF	Chaparral, ponderosa pine, mixed conifer	Watershed management	Total—13,255 acres; Federal, 13,213; State, 42
COLORADO				
BLACK MESA 1954—Initiated experimental work 1963—Established as an experimental forest, February 8 1975—Inactive	Gunnison County, Gunnison NF	Mountain grassland	Range, wildlife, and watershed management	Total—4,799 acres; Federal, 4,258; Private, 541
CENTRAL PLAINS 1937—Established as an experimental range, July 26 1954—Transferred to Agricultural Research Service 1975—Active under ARS	Weld County, Pawnee National Grasslands	Shortgrass Plains	Range management	Total—10,880 acres; Federal, 10,560; Private, 320

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
FRASER 1937—Established as an experimental forest, August 26 1975—Active	Grand County, Arapaho NF	Lodgepole pine, spruce-fir	Watershed, timber, and multiple use management	Total—23,000 acres; all Federal
FREMONT 1909—Initiated experimental work 1931—Established as an experimental forest, September 17 1975—Inactive	El Paso County, Pike NF	Mixed conifers	Timber management	Total—1931 to 1956, 500 acres; reduced to 260 acres April 12, 1956; all Federal
MANITOU 1938—Established as an experimental forest, March 25 1975—Active	Teller, Douglas, El Paso Counties, Pike NF	Ponderosa pine, bunchgrass	Range, watershed, and multiple use management	Total—16,560 acres; Federal, 14,500; Private, 2,060
REDFEATHER 1968—Established as an experimental forest, February 2 1975—Active	Larimer County, Roosevelt NF	Ponderosa pine, lodgepole pine, spruce-fir	Insect and disease biology, ecology, and control	Total—2,285 acres; all Federal
NEW MEXICO				
CLOUDCROFT 1925—Initiated experimental work 1935—Established as an experimental forest, November 30 1975—Inactive	Otero County, Lincoln NF	Douglas-fir	Timber management	Total—2,120 acres; all Federal
JORNADA 1912—Established as a range reserve by Bureau of Plant Industry 1915—Transferred to Forest Service 1954—Transferred to Agricultural Research Service 1975—Active under ARS	Dona Ana County	Semidesert grass-shrub	Range management	Total—193,394 acres; all Federal
NORTH DAKOTA				
DENBIGH 1931—Initiated experimental work 1961—Established as an experimental forest, June 20 1975—Active	McHenry County, USDA Forest Service	Northern Plains grassland	Shelterbelt management	Total—640 acres; all Federal
SOUTH DAKOTA				
BLACK HILLS 1961—Established as an experimental forest, October 6 1975—Active	Lawrence and Pennington Counties, Black Hills NF	Ponderosa pine	Timber and wildlife management	Total—3,438 acres; all Federal

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
B. Areas used for experimental purposes under cooperative agreement, or other arrangement				
ARIZONA				
BEAVER CREEK 1957—Initiated experimental work 1975—Active	Coconino and Yavapai Counties, Coconino NF	Desert shrub, pinyon-juniper, ponderosa pine	Watershed, and multiple use management	Total—275,000 acres; nearly all Federal
CASTLE CREEK 1956—Initiated experimental work 1975—Active	Greenlee County, Apache NF	Ponderosa pine	Watershed management	Total—2,063 acres; Federal, 1,953; State, 110
MINGUS MOUNTAIN 1958—Initiated experimental work 1975—Active	Yavapai County, Prescott NF	Chaparral	Watershed management	Total—205 acres; all Federal
SEVEN SPRINGS 1964—Initiated experimental work 1975—Active	Apache County, Apache NF	Mountain grassland	Watershed management	Total—1,200 acres; all Federal
THREE-BAR 1956—Initiated experimental work 1975—Active	Gila County, Tonto NF	Chaparral	Watershed management	Total—290 acres; all Federal
TONTO SPRINGS 1961—Initiated experimental work 1970—Research terminated; area returned to Prescott NF	Yavapai County, Prescott NF	Chaparral	Range management	Total—1,260 acres; all Federal
WILD BILL 1962—Initiated experimental work 1974—Research terminated; area returned to Coconino NF	Coconino County, Coconino NF	Ponderosa pine	Range management	Total—1,300 acres; all Federal
WHITE SPAR 1958—Initiated experimental work 1975—Active	Yavapai County, Prescott NF	Chaparral	Watershed management	Total—549 acres; all Federal
WILLOW-THOMAS CREEKS 1963—Initiated experimental work 1975—Active	Greenlee County, Apache NF	Mixed conifer	Watershed and multiple use management	Total—1,816 acres; all Federal

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
COLORADO				
BADGER WASH 1953—Initiated experimental work 1966—Forest Service research terminated 1975—Active research continuing under direction of U.S. Department of the Interior agencies	Mesa County	Shadscale	Range, wildlife, and watershed management	Total—399 acres; all Federal (Bureau of Land Management)
CRAWFORD NURSERY 1948—Initiated experimental work 1954—Transferred to Agricultural Research Service 1975—Inactive	Delta County	Sagebrush, pinyon-juniper	Range reseeding	Total—2 acres; all private
WAGON WHEEL GAP 1909—Initiated experimental work 1926—Research terminated; area returned Rio Grande NF	Mineral County, Rio Grande NF	Spruce-fir, aspen	Watershed management	Total—400 acres; all Federal
NEBRASKA				
HALSEY 1963—Initiated experimental work 1975—Active	Thomas County, Nebraska NF	Central Plains grassland	Nursery diseases control, and tree improvement	Total—20 acres; all Federal
HASTINGS 1968—Initiated experimental work 1975—Active	Adams County, Forest Service acquisition from GSA	Central Plains	Tree improvement, and disease evaluation	Total—144 acres; all Federal
HORNING STATE FARM (Univ. Nebr.) 1959—Initiated experimental work 1975—Active	Cass County	Tall grass prairie, Central Plains	Tree improvement, and biology and control of conifer foliage diseases	Total—240 acres; all State
MEAD UNIVERSITY FIELD LABORATORY 1970—Initiated experimental work 1975—Active	Saunders County	Central Plains	Tree improvement	Total—20 acres; all State
NORTHWEST AGRICULTURE LABORATORY (Univ. Nebr.) 1968—Initiated experimental work 1975—Active	Box Butte County	Central Plains	Tree improvement, and disease evaluation	Total—12 acres; all State

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
NEW MEXICO				
CIBOLLA MESA 1950—Initiated experimental work 1975—Inactive	Taos County	Sagebrush, pinyon, and juniper	Range reseeding, and cattle regrazing	Total—150 acres
FORT BAYARD 1961—Initiated experimental work 1975—Temporarily inactive	Grant County	Pinyon-juniper	Deer and elk range studies	Total—10,250 acres;
NO AGUA 1952—Initiated experimental work 1975—Inactive	Rio Arriba County	Open ponderosa pine	Range reseeding, and cattle grazing	Total—30 acres;
SAN LUIS 1952—Initiated experimental work 1972—Research terminated; area returned to Bureau of Land Management	Sandoval County	Pinyon, juniper, semidesert	Watershed and range management	Total—1,364 acres; Federal, 1,204 Private, 160
TANK CANYON 1956—Initiated experimental work 1975—Inactive	Rio Arriba County	Sagebrush, pinyon-juniper	Range reseeding, and sheep grazing	Total—200 acres;
SOUTH DAKOTA				
STURGIS 1961—Initiated experimental work 1975—Active	Meade County, Black Hills NF	Ponderosa pine	Watershed management	Total—496 acres; all Federal
WYOMING				
BEAVER RIM 1949—Initiated experimental work 1975—Inactive	Fremont County	Sagebrush	Sagebrush controls	Total—363 acres;
BURGESS 1959—Initiated experimental work 1972—Research terminated; area returned to Bighorn NF	Sheridan County, Bighorn NF	Mountain grassland	Range management	Total—350 acres; all Federal
CARTER MOUNTAIN 1963—Initiated experimental work 1975—Active	Park County, Shoshone NF	Alpine tundra	Range management	Total—3,840 acres; all Federal

	Location	Vegetation type	Primary research emphasis	Size (acres) and land ownership
WYOMING (continued)				
DUBOIS 1958—Initiated experimental work 1972—Research terminated; area returned to Shoshone NF	Fremont County, Shoshone NF	Mountain sagebrush	Watershed management	Total—300 acres; all Federal
INTERSTATE HIGHWAY 80 1970—Initiated experimental work 1975—Active	Albany and Carbon Counties	Sagebrush shortgrass	Blowing snow control	Total—90,000 acres; of mixed ownerships
POLE MOUNTAIN 1960—Initiated experimental work 1973—Research discontinued 1975—Inactive	Albany County, Medicine Bow NF	Shortgrass	Watershed, and wildlife habitat	Total—300 acres; all Federal
STRATTON 1967—Initiated experimental work 1975—Active	Carbon County, Bureau of Land Management	Sagebrush	Watershed management	Total—7,160 acres; Federal, 6,300; State, 860



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1976. History of Forest Service Research in the Central and Southern Rocky Mountain Regions, 1908-1975. USDA For. Serv. Gen. Tech. Rep. RM-27, 100 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

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on Colorado State University
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dedicated July 28, 1967.*



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Biology and Management of Threatened and Endangered Western Trouts



August 1976

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Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

Abstract

Behnke, R. J., and Mark Zarn.

1976. Biology and management of threatened and endangered western trouts. USDA For. Serv. Gen. Tech. Rep. RM-28, 45 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Discusses taxonomy, reasons for decline, life history and ecology, and suggestions for preservation and management of six closely related trouts native to western North America: Colorado River cutthroat, *Salmo clarki pleuriticus*; green-back trout, *S. c. stomias*; Lahontan cutthroat, *S. c. henshawi*; Paiute trout, *S. c. seleniris*; Gila trout, *S. gilae*; and Arizona native trout, *S. apache*. Meristic characters, distribution and status, habitat requirements and limiting factors, protective measures, and management recommendations are presented for each taxon.

Keywords: Native trout, *Salmo clarki pleuriticus*, *Salmo clarki stomias*, *Salmo clarki henshawi*, *Salmo clarki seleniris*, *Salmo gilae*, *Salmo apache*.

Biology and Management of Threatened and Endangered Western Trouts

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BIOLOGY AND MANAGEMENT OF THREATENED AND ENDANGERED WESTERN TROUTS

INTRODUCTION

This report discusses the biology and management of six closely related trouts native to western North America. All share many common ecological and genetic attributes; all have suffered catastrophic declines in abundance due to essentially similar factors. The following section presents general information applicable to all of these trouts and relevant to any meaningful preservation, restoration and management efforts. Succeeding chapters present more specific biological and management considerations for each taxa.

TAXONOMY

Man still lacks complete knowledge of the evolutionary history which resulted in the diverse array of western North American trouts of the genus Salmo. Earlier thought considered that all western trouts either belonged to or recently derived from two evolutionary lines or species: the rainbow trout, Salmo gairdneri, and the cutthroat trout, S. clarki. Recent studies have demonstrated that the true situation is much more complex; several distinct groups including the Gila trout (S. gilae), Arizona native trout (S. apache), Mexican golden trout (Salmo chrysogaster), California golden trout (Salmo aguabonita) and redband trout (not officially named) do not fit the diagnosis of either the rainbow trout or the cutthroat trout and probably represent distinct evolutionary lines of their own which sprang from a common ancestor to all western Salmo (Behnke 1972b, Schreck and Behnke 1971, Miller 1972).

Despite such evolutionary diversity, all western trouts are closely related to the extent that they can interbreed freely with each other to produce fertile hybrids. Only in Pacific Coast rivers, where rainbow trout and the coastal cutthroat, S. c. clarki, reside together and in the Salmon and Clearwater drainages of the Columbia River basin of Idaho where resident interior cutthroat

occur with anadromous steelhead trout (S. gairdneri) does coexistence occur naturally without hybridization. In all instances where the rainbow trout has been established beyond its native range and stocked with Gila trout, golden trout or any of the interior subspecies of cutthroat trout, hybridization has invariably resulted. The indiscriminate stocking of untold millions of rainbow trout and several subspecies of cutthroat trout into virtually every habitable water throughout the West, and subsequent hybridization with the native trout fauna, has been the primary cause for the almost complete elimination of pure populations of most of the taxonomic categories of native trouts in the interior regions of the West.

The presence of all degrees of hybridization greatly confounds the work of correctly identifying and evaluating the purity of existing populations of native trout in most regions, and the recognition of pure stocks of any of the six trouts considered in this report is not a simple matter. Although one can acquire sufficient familiarity with the subtle variations among the different species and subspecies of western trouts to distinguish the various taxa, the average field worker cannot be expected to accurately differentiate the true native trout of a given area from hybrid populations. Taxonomic criteria exist for all the trouts in this report, but the sorting and evaluation of specimens collected during survey work to determine the status of a native trout and to locate pure populations remains an involved process of detailed examination and comparison of many characters.

So unless an agency is dealing with "certified" pure populations in a rare trout management program, it will ultimately confront the problem of identification. Possibilities for additional refinement of information useful in taxonomic identification exist; these include biochemical techniques such as protein electrophoresis and karyotype examination--the determination of chromosome number and morphology. Yet the investigator should use caution in utilizing these modern techniques

to determine the relative purity of trout populations, for they require both a knowledge of basic principles of taxonomy and a familiarity with the natural range of variability of the trout under study. Often, if the extent of hybridization has reached a level where it can be detected by electrophoresis or alterations in the chromosome complement, it will also show up in the form of changes in dentition, spotting pattern, scale counts and other morphological characters.

The lack of reproductive isolation and the lack of clear-cut diagnostic features, has raised questions concerning the validity of the recognized taxa of western trouts. The most pertinent advice relevant to management policies for any trout under consideration is to ignore or avoid questions concerning the validity of zoological nomenclature, while recognizing that each of these trouts is indeed an evolutionary reality. That is, it has become an integral part of the biological and evolutionary heritage of a given geographical area as a result of its unique genetic programming under the natural selection which has taken place during its long isolation and divergence from ancestral trout fauna. All of the six taxa of trout discussed in this report fall within the province of the Endangered Species Act of 1973 (P.L. 93-205) which defines a species to include "subspecies, smaller taxa or any population segment thereof." Thus, the validity of a species or subspecies should not obstruct protective measures for a rare trout; the major consideration ought to be that the trout represents a segment of a species indigenous to a particular geographical area.

Behnke (1972a) and Trojnar and Behnke (1974) have discussed the rationale and practical value of preserving the remaining genetic diversity of our native western trouts.

REASONS FOR DECLINE

We mentioned that the hybridization caused by massive introduction of rainbow trout and subspecies of cutthroat trout into waters in which they were not native has led to the virtual elimination of pure populations of the trouts under discussion in this report. Habitat loss and degradation as a result of irrigation projects, mining, logging, road building and overgrazing have also taken their toll, particularly in the arid regions of the West. These factors have not only greatly reduced the amount of suitable habitat, but

also favor the displacement of native trouts by more tolerant introduced species, notably the brook trout (Salvelinus fontinalis) and the brown trout (Salmo trutta).

Most pure native trout populations in the interior regions of the West persist only in small isolated headwater stream situations in essentially undisturbed habitat.

LIFE HISTORY AND ECOLOGY

All of our western trouts are highly adaptable; they can live in a variety of environments ranging from small brooks to large rivers and lakes, and they feed on a broad spectrum of organisms. This wide range of adaptability makes it highly misleading to base the ecological characteristics of an entire taxon on data taken from a population in a specific habitat. All trouts are opportunistic and eclectic in their diet, which essentially reflects the availability of food organisms in their particular environment. Growth depends primarily on food availability, size of prey, the degree of intraspecific and interspecific competition, water temperatures, and the length of the growing season. Fecundity, in turn, depends on size. The life history and ecological traits of two neighboring populations of the same subspecies living in distinctly different environments will differ much more from each other than from those of different trout species living in essentially similar environments. One must be aware that different genotypes allow for a broad and labile range of ecological options; to assume that specific food habits, growth rate, fecundity or other characteristics of a given population under study represent genetically "fixed" attributes of the taxon as a whole is a misconception. The significance of this point in relation to restoration efforts which aim to expand the range of a rare trout is that waters with potential for reintroduction need not closely match the conditions of the waters of the potential donor population. With the condition that no non-native trouts are present, virtually any waters suitable for any trout species can serve as suitable habitat for any of the six trouts treated in this report. One notable exception in adaptability to environmental extremes exists in the Lahontan cutthroat trout, which can tolerate tremendous ranges in alkalinity and flourish in waters such as Walker Lake, Nevada, under conditions lethal to all other trouts.

All of the non-domesticated western trouts of the genus Salmo spawn in the spring; increasing water temperatures trigger reproduction. Most spawning activity begins when

water temperatures reach 5.5 - 9.0° C. Elevation and latitude also influence the onset of spawning, which may occur as early as March or April in some areas and extend well into June and July in others. The necessity of gravel for nest construction and high oxygen tensions for the developing embryos makes all of the trouts under consideration essentially obligatory stream spawners. Fry emerge from nests in early to mid-summer, depending on when spawning occurs; length of the growing season dictates size, which reaches 2.5 to 7.5 cm by autumn. Fish six to eight years old may attain a length of less than 25 cm in small streams with restricted habitats and dense populations, but in large rivers and lakes growth can be rapid with trout reaching several pounds in weight by the fourth or fifth year. The last spawning run, in 1938, of the native cutthroat of Pyramid Lake, Nevada, revealed an average weight of 9.0 kg for spawning fish, most of which were seven to eight years old (Sumner 1940); trout of the same subspecies living in headwater streams may not exceed 25 cm in length.

Sexual maturity typically occurs at an age of two to four years. In small stream populations mature trout may only be 15 to 20 cm in length and spawn only 100-200 eggs. A generalization on fecundity, with wide individual variation, is that females will spawn about 1000 eggs per 450 gms of body weight.

Present populations of these trout probably cannot persist in waters where maximum temperatures consistently exceed 21-22° C. But they may possess tolerance to survive, under stress, brief daily periods of higher temperatures (25.5 - 26.7° C.) if the waters significantly cool at night. The pattern of replacement of native trouts by introduced brook, brown and rainbow trout throughout the interior West indicates that the native trouts prefer and function best at lower temperatures than do other species. With few exceptions, native cutthroat trout coexist with and dominate introduced species only in cold, headwater situations. Thus, clearcutting and overgrazing, which remove vegetative cover and warm the waters, will favor the replacement of native trouts by other forms.

In Oregon, after clearcutting of a watershed, water temperatures increased due to lack of cover, and dissolved oxygen in the spawning gravel decreased due to siltation. This did not significantly affect the coho salmon population, but the cutthroat trout population suffered a decline of two-thirds in number during six years of a follow-up study (Ringler and Hall 1975).

Cutthroat trout, and perhaps Gila trout and Arizona trout as well, suffer from a high vulnerability to angling. In a small Idaho stream, 32 man-hours of fishing removed 50 percent of the cutthroat trout and only 25 percent of the brook trout 15 cm and over in length (McPhee 1966). In New Mexico the native trout of the Rio Chiquito dominated the introduced brown trout by 420 to 37 in samples made in 1965-1966, when the stream was on private land and closed to fishing (Little and McKirdy 1968). In 1969, two years after the U. S. Forest Service had acquired the land and opened the stream to angling, sampling revealed that the ratio had been drastically reversed--137 brown trout versus 37 cutthroat trout--due to the differential vulnerability of the two species to angling^{1/}. Management programs for native trout can benefit from this angling vulnerability, however, by establishing special regulation catch-and-release fisheries, or by restricting size and bag limits, as discussed below (see pages 7-8).

PRESERVATION, RESTORATION AND MANAGEMENT PROGRAMS

It often seems difficult to initiate meaningful rare trout restoration programs, but while real problems and obstacles exist, workers can overcome them if they develop a set of priorities and goals and recommend that specific actions be carried out. It remains a relatively simple matter to transplant trout from a remnant population into new waters--either barren or where all other fish have been eliminated--in order to establish a new population.

The first step in most restoration programs for rare, native trout--that of identification--involves a survey and inventory of waters where there is a likelihood of encountering pure populations. Remote and isolated headwater areas, particularly above barrier falls and without tributary lakes (which serve as popular target areas for introductions of exotic trouts), offer the greatest potential for native trout population reserves. When trout in such waters appear to resemble the diagnosis of the native trout, collect 10-20 specimens from each isolated site and preserve them in 10 percent formalin. In the field, wrap specimens in formalin-soaked cloth and inject formalin into the body cavity with a hypodermic syringe. Comparative examination of these collections can begin to identify

^{1/} McKirdy, H. J. Rio Chiquito population survey. Carson National Forest memorandum. 22 August 1969.

those populations most closely conforming to the diagnosis of the taxon involved. Graduate research thesis projects through universities can offer relatively efficient and economical means of handling survey and identification work. Once researchers establish the relative purity, distribution and abundance of the native forms, those populations judged to be uncontaminated by hybridization can be given special consideration in land use decisions and environmental impact analysis, and serve as a source for specimens for introductions to increase their abundance.

Unnecessary delays and procrastination typically begin at this stage, when specific native populations have been identified. Many believe that they must initiate life history and habitat studies before any management decisions or transplants can take place. The objectives are to gather detailed data on age, growth, food habits, fecundity and other life history characteristics of the trout population, and on the biological, physical and chemical parameters of the waters in which they live, with the idea that once this knowledge becomes available intelligent and scientific management can begin. If the life history characteristics of trout were genetically fixed traits, and if the environmental parameters measured composed a true reflection of the limits for survival, this would be a logical course of action; but in fact they are not. Such information usually has little meaning when predicting the success of a transplant into new waters, except where basic information is needed to maintain an abundance of trout and a desirable age structure in a population exposed to exploitation in a special regulations fishery program.

If a survey determines that pure populations of a native trout are rare and restricted to a few isolated stocks, then first priority should be to effect transplants into new waters within their native range, before natural or man-caused catastrophes can further decimate the remnant stocks. After the establishment of populations in new waters, life history studies and environmental analyses can include both donor and recipient populations and their environments. Such information would have greater predictive value since it would offer more insight into the range of adaptive responses of the trout under study.

Naturally barren waters above barriers, which prevent mixing with introduced trouts, constitute ideal sites for establishing new populations. Such locations still exist, though they are rare. The expense and efforts of effecting a transplant of this nature involves only the collection and transport of

live fish. Note that some barren headwater streams, particularly at high elevations, appear to provide suitable habitat for trout in summer, but lack pools and cover sufficient to successfully carry the fish through a hard winter. In these situations the trout migrate from the area and will not maintain a permanent population (Bjornn 1971). Habitat improvement in headwater areas is feasible when it involves creating pools and cover to provide support for a permanent fish population (Gard 1961, 1972).

Many more streams exist which support introduced trouts or hybrids above a natural barrier; they too offer good possibilities for establishment of native trout populations with minimal effort and expense. No doubt exists that these streams can support the transplanted trout after the complete elimination of all other fish. Use antimycin or rotenone in small streams to completely kill all fish, taking care to treat all possible refuge areas such as backwater areas of beaver ponds and spring seeps. The National Park Service used this technique in Rocky Mountain National Park in eliminating the brook trout from Hidden Valley to re-establish the greenback cutthroat trout.

If no natural barrier exists on an otherwise suitable stream, it is possible to construct an artificial barrier or to blast one out of a rock substrate. Follow barrier construction with chemical treatment above the stream, to eliminate unwanted fishes, before the introduction of native trout. Workers used this technique to re-establish greenback trout in Black Hollow Creek, Colorado, and Gila trout in McKnight Creek, New Mexico.

Another viable possibility in any rare trout reintroduction program is the establishment of populations in newly constructed lakes to establish a unique fishery under special regulations. Christmas Tree Lake on the Apache Indian Reservation, Arizona, stocked with Arizona native trout, serves as an example of this method. Lake populations offer an abundant and easily obtainable source of eggs for propagation, and can greatly facilitate new introductions.

Some difficulties may exist in establishing a new population from transplants of a few adult fish into a new environment, particularly in small headwater streams without deep pools above a barrier. The natural tendency of a displaced fish is to return to the place of its origin, and most may soon migrate downstream over the barrier. Trout movement is also more pronounced during periods of low or decreasing temperatures (Bjornn 1971). Once

natural reproduction has occurred in the new environment, the success of the introduction should be assured, barring some catastrophe.

Particularly in arid regions where streams characteristically display intermittent summer flows and lack suitable pools and cover, stream improvement devices can promote increased abundance of trout by creating trout habitat where none previously existed. Stream improvement devices often require a considerable investment of money, time and labor, but the construction in the 1930's of such devices in Diamond Creek, New Mexico, by Civilian Conservation Corps personnel may have saved the Gila trout in this stream from extinction during subsequent drought years when virtually the entire population was restricted to the pools created by the small dams.

Successful stream habitat management improves living conditions in the waters and increases survival, growth and reproduction of trout. Good trout habitat provides shelter from predators, fertile water, adequate living space, proper water temperature, and gravel in the streambed for spawning. Proper stream management, especially when it involves the construction of in-stream improvement devices, is both relatively expensive and relatively complicated, and remains a job for professionals who are both well-versed in fundamental trout ecology and familiar with habitat management techniques. Every stream has its individual problems and characteristics, and to proceed with habitat alteration projects to "improve" a stream without a thorough knowledge of available methods, the physical, chemical and biological parameters of the waters in question, and the ecological characteristics of the resident fish population, can do more harm than good. A habitat improvement team should consist of biologists skilled in habitat development, technicians familiar with surveying and mapping techniques, and foremen experienced in carpentry and mechanics (White and Brynildson 1967). Space does not permit a thorough discussion of habitat improvement techniques here; several excellent papers exist to familiarize personnel with this topic (see: Boreman 1974, Packer 1957, Jester and McKirdy 1966, Gee 1952, Hunt 1969, White and Brynildson 1967, Jackson 1974).

A survey of streams in an area to locate those having potential for improvement constitutes the first step in an orderly management sequence. Examination of streams should proceed on an individual basis and take into account the characteristics of the entire stream course, and not just those sections obviously in need of management. In this way many problems can be avoided, such as

construction of pools over the only adequate deposits of spawning gravel in the stream. Diagnosis of specific problems in the stream leads to a prescription of treatment methods and their sequence. Implement first those treatments which have the greatest positive effect for the least expenditure of money and effort. A logical concluding step, but one that may be overlooked, consists of following treatment with an orderly program of inspection and maintenance (White and Brynildson 1967).

Do not fail to consider either the fertility of the water or the year-round carrying capacity of a stream which otherwise appears to have potential for improvement. Habitat manipulation aimed at increasing cover in a stream will prove of little value in providing more trout either if production is limited by a lack of nutrients or if the carrying capacity of the stream is drastically reduced at some season, as by freezing in winter or flooding in spring, thereby negating any effects of increased summer production (White and Brynildson 1967).

Protecting natural stream habitat best guarantees the perpetuation of native trout populations. The most significant habitat in small to moderate-sized streams consists of undercut banks, which in turn depend on extensive vegetative cover of the exposed bank (Wesche 1973). Livestock overgrazing presents the greatest threat to the integrity of headwater stream habitat quality in the West. Grazing livestock may destroy the vegetative cover and cave in overhanging banks, thereby eliminating the most important trout habitat. Loss of streambank vegetation leads to increased water temperatures, erosion and silting, elimination of spawning sites and reduction of food supplies in the stream, all of which drastically degrade trout habitat.

Guidelines have been developed to minimize damage to streams from logging, road building and mining operations; if they are conscientiously followed, good trout populations can be maintained in watersheds subject to these uses. The major multiple-use problem yet to be adequately treated on National Resource Lands, however, is the impact of livestock grazing on aquatic habitat. This problem is particularly acute in arid regions, where livestock often tend to concentrate in riparian vegetation along stream banks. Their impact on trout habitat can be devastating.

Although lack of riparian vegetation, caved-in banks, erosion, and siltation are readily visible results of overgrazing, quantitative data documenting such damage are not abundant. Gunderson (1968) reported on the fish popula-

tions in comparable grazed and ungrazed sections of Rock Creek, Montana. In 1964, 126.6 kg/ha of wild brown trout occurred in the grazed section and 167.8 kg/ha in the ungrazed section. Trout above 30 cm in length were more than three times as abundant in the ungrazed section. The major habitat differences between the grazed and the ungrazed sections concerned riparian vegetation, bank stability and average stream channel depth. The grazed segment of the stream consisted of a spread-out channel with mainly shallow riffle areas; it lacked deep pools and undercut banks. By 1970 the differences between the two stream segments were even greater. Biomass of wild brown trout had declined to 71 kg/ha in the grazed section, while it increased in the ungrazed part of the study area to 238.9 kg/ha. Interestingly, investigators found more mountain whitefish (Prosopium williamsoni) in the grazed than in the ungrazed section. The mountain whitefish, often accused of being a serious competitor with trout, more likely is just better adapted than trout to utilize disturbed habitat. In the natural, ungrazed section of the stream, whitefish comprised only 10 percent of the total fish biomass, whereas in the altered grazed habitat they made up 35 percent of the total fish biomass (Marcuson 1970).

The need for more precise data on the relationships of livestock density and grazing techniques to soil, climate, vegetation and impacts on stream environments and fish populations must be considered as the highest research priority to provide a sound basis for management decisions which will resolve the conflicts between livestock grazing and fish habitat quality.

The Intermountain Forest and Range Experiment Station of the U. S. Forest Service at Boise, Idaho has initiated a 10-year study titled "The effects of livestock grazing in high mountain meadows on aquatic environments, streamside environments and fisheries," under the direction of Dr. William Platts, who has studied livestock impacts on streams for many years. In an earlier report^{2/} he raised significant questions on the efficacy of rest-rotation grazing management for restoring streambank vegetation and rehabilitating unstable banks. Platts observed that, while one year of rest may be sufficient to restore pasture grass, it may not be sufficient time to enable previously overgrazed streambank shrubs to recover.

^{2/}Platts, W. and C. Roundtree. 1972. Bear Valley Creek, Idaho. Aquatic environment and fishery study. USDA Forest Service, unpubl. rept. 46 p.

Dr. Platts' research should provide a factual basis for multiple use management and more harmonious coexistence of livestock and trout populations. It would be a mistake, however, to delay attempts to reverse stream habitat deterioration 10 years while awaiting the outcome of the study. As a starting point, a recommendation in the Bureau of Land Management's environmental impact statement on grazing in Nevada (USDI Bureau of Land Management 1974) should be implemented, namely that costs for protecting critical environments, such as streams and riparian vegetation, be assumed by the interests causing the damage. If a rare trout restoration program is to be successful where the habitat is exposed to grazing, an integral part of the program must consist of strict grazing controls and watershed protection.

For background information on the actual or potential impact of various land-use practices on trout streams, see: Burns 1970, Cordone 1956, Cordone and Kelley 1960, Elser 1968, Megahan and Kidd 1972, Mullan 1975, Platts 1974, U.S. Forest Service 1975, White 1975, Gibbons and Salo 1973, and Grove 1976.

The U. S. Forest Service, Region VI, Portland, Oregon, is currently developing a fish habitat management policy which will include guidelines on:

- I. Fish habitat protection and restoration
 - A. Timber management and road construction
 - B. Livestock grazing
 - C. Mining
- II. Fish habitat enhancement

The section on timber management and road construction has been completed. The section on livestock grazing is in draft form, scheduled for completion by July 1976. Other sections have not yet been started. The Oregon chapter of the American Fisheries Society passed a resolution endorsing this habitat management policy and urging its adoption on a nationwide basis (American Fisheries Society Newsletter, March-April, 1975).

POTENTIAL ROLE OF NATIVE TROUT IN FISHERIES MANAGEMENT

At first glance, the idea of promoting angling for a rare trout while the goal of the program is to increase its abundance may appear contradictory. Actually, though, the major hope for increasing the abundance of a rare trout lies in re-establishing it in waters, within its native range, where it has been extirpated or hybridized. In all likeli-

hood, such sites are now public fishing waters. State game and fish agencies funded by angler license fees may be understandably reluctant to close public fishing waters in order to re-establish a native trout population which would be fully protected from angling. No rare or endangered trout has become so through overfishing; the fear that fishermen might exterminate a population is simply not based in fact. Properly publicized, native trout can be used in unique, quality fisheries with virtually no expense, if populations reproduce naturally. Fishermen often place a higher recreational value on the opportunity to fish for a native trout than for a hatchery trout.

Special regulations for native cutthroat in Idaho test streams include a catch-and-release fishery and a 33-cm minimum size limit. The abundance, average size and catch-per-hour of trout in the stream have all increased under these regulations (Ball 1971, Bjornn and Thurow 1974, Hogander et al 1974). The National Park Service initiated a catch-and-release fishery on the Yellowstone River in Yellowstone National Park in 1973 after comparisons had shown that 309 cutthroat trout sampled in a closed section averaged 44.7 cm, against 36.1 cm for 378 trout from the open-fishing area. The catch-per-hour under the special regulations increased by two- to four-fold over the previous four years; most fishermen were enthusiastic over the change (Jack Dean, personal communication to Robert Behnke).

The research of Dr. Ted Bjornn, leader of the Idaho Cooperative Fishery Unit, has provided the best evidence of the potential of native cutthroat trout to produce a high quality fishery under special regulations. In 1971 investigators attempted to restore the abundance of the native trout in several miles of the upper St. Joe River, Idaho, by cessation of hatchery rainbow trout stocking and institution of an artificial lure fishery with a minimum size limit of 33 cm. Studies from 1968 to 1970 had revealed that the cutthroat was suffering heavy angling exploitation. Cutthroat trout caught by fishermen averaged only slightly over 17.8 cm; only 2.5 percent of the population exceeded 25 cm and only 0.1 percent exceeded 33 cm. The results of this management program have proved very encouraging. Rainbow trout have virtually disappeared from the unstocked area. Cutthroat trout increased from three- to six-fold in abundance in areas under special regulation, and without stocking. Average size of fish caught by anglers increased 5 cm in the first two years. The proportion of fish longer than 25 cm increased by 1000 percent; those over 33 cm increased by 3000 percent. The number of cutthroat caught increased by over

four times--8100 after institution of special regulations versus 1800 before--and the catch-per-man-hour increased by six times, from 0.8 to 4.8, when comparing data of 1973 with that of 1968 in one five-mile stream section (Bjornn 1975). With the 33-cm minimum size limit, anglers kept many fewer cutthroat, but because of the greatly increased average size, the total weight of cutthroat trout creeled has probably not changed greatly. Angler response to the native cutthroat fishery has generally been quite supportive and by 1974, the stream enjoyed the same intensity of use that it had prior to the institution of special regulations, when heavy stocking of catchable rainbow trout supported the fishery. And so by protection from excessive exploitation, a more valuable fishery based solely on natural reproduction of a native trout has replaced a more expensive catchable trout fishery and the vulnerability of the cutthroat trout to repeated catching has resulted in a greatly increased catch rate.

Basically, the design of a special regulations fishery assumes that a natural trout population will undergo a "stockpiling" effect if smaller trout are protected from fishing exploitation and allowed to survive to a larger size. Most detailed studies of wild trout populations in streams have shown that special regulations designed to produce more and larger trout by restricting the catch do not work (Allen 1951; Hunt 1966, 1970; Latta 1973; Klein 1974). But most of these studies concerned brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta). In these species, the lack of response to restricted catch results from the fact that habitat characteristics and food supply govern natural mortality rates and age-size structure of the populations. Typically, the above studies demonstrated that the overwhelming majority of production and biomass--from 70 to 90 percent--remained tied up in the 0 and I age groups (trout of sub-catchable size) and that about 98 percent of all trout hatched died from natural causes before they reached catchable size, typically in age group II+. Under circumstances where all age groups compete for a common food supply, and where sub-catchable trout constitute the bulk of the biomass, attempts to change the age and size structure of the population either by protecting it from angling or conversely, to promote angling in the hopes of stimulating growth in the fishes that remain, will have little effect on the population as a whole. This is because such a small segment of the total population is exposed to removal by angling, and because mortality is compensatory. That is, reduced angling mortality results in increased natural mortality; therefore the annual survival rate of trout of any year class remains approximately

the same whether the fish are protected or unprotected from angling.

Why, then, have the cutthroat trout populations mentioned above apparently responded to special protective regulations and exhibited a "stockpiling" effect? Three major factors are likely involved.

1. In all of these areas investigators speculate, but have not conclusively demonstrated, that the spawning and rearing areas exist apart from the main fishing areas. This reduces or eliminates the intraspecific competition between the younger, sub-catchable age groups, and the older, larger trout.

2. The vulnerability of the cutthroat trout to angling results in a higher catch-per-man-hour from cutthroat trout than from other species. No one knows how many times a trout might be caught and released in any given fishery, but Webster and Little (1947) reported that 200 rainbow trout stocked in an enclosed section of stream yielded a catch (when released) of 601 in 54 days--each trout was caught an average of three times. All studies to date have revealed virtually no (under five percent) mortality in trout released from artificial flies and lures.

3. In the studies on brook trout cited above, virtually no trout survived to age class IV or V. In most cutthroat trout populations, maximum ages of VI or VII appear rather commonly. Subsequent survival of older age groups results in a higher ratio of catchable-size to smaller sizes in cutthroat trout populations when compared to populations of typically short-lived brook trout.

A higher annual survival of older age groups (age II and older) indicates a decrease in natural mortality. Where angling mortality becomes high in such a situation, it may exceed natural mortality and depress the population below the carrying capacity of the environment. Temporary protection from angling, or a lowering of the creel limit in such instances, would result in higher annual survival and an increase in numbers.

Stream modification to produce more shelter and deeper water can increase the proportion of older to younger trout, food utilization, biomass and angler catch. Hunt (1969) demonstrated the efficacy of stream modification in Lawrence Creek, Wisconsin.

Generally, special regulations work best for a trophy fishery and require moderate to large rivers or lakes where food and space permit rapid growth and attainment of a large

size. Virtually all fish in a small stream may die of old age before reaching a length of 25 cm. Most streams holding pure populations of rare, native trout are too small and remote from civilization to attract more than negligible fishing pressure; special angling restrictions are not justified under such circumstances. The Province of Alberta, Canada, has instituted management regulations for small streams containing cutthroat trout which consists of closing the streams in alternate years to allow a buildup of larger trout (Radford 1975).

SUMMARY

Steps in a native trout management program may consist of:

1. Survey of waters to collect specimens from suspected pure populations and to locate potential sites for re-introduction.

2. Taxonomic study of collections to identify pure populations.

3. Protection and possible improvement of habitat.

4. Introduction into barren or chemically treated waters isolated by some barrier against contamination by non-native trouts.

5. Establishment of special regulation fisheries where applicable.

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REFERENCES

- Allen, K. R.
1951. The Horokiwi stream: a study of a trout population. New Zealand Marine Dept., Fish. Bull. 10.
- Ball, K.
1971. Evaluation of catch-and-release regulations on cutthroat trout in the North Fork of the Clearwater River. Idaho Fish and Game Dept., Job Completion Report F-59-R-2. 37 p.
- Behnke, R. J.
1972a. The rationale of preserving genetic diversity. Proc. West. Assoc. of State Game and Fish Comm. 52:559-561.
-
- 1972b. The systematics of salmonid fishes in recently glaciated lakes. Jour. Fish. Res. Bd. Canada 29(6):639-671.
- Bjornn, T. C.
1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover and population density. Trans. Am. Fish. Soc. 100(3): 423-438.
-
1975. The St. Joe River cutthroat fishery-- a case history of angler preference. Proc. West. Assoc. State Game and Fish Comm. In press.

- _____, M. A. Brusven, M. Molnau, F. J. Watts and R. L. Wallace.
1974. Sediment in streams and its effect on aquatic life. Water Resources Res. Inst., Univ. Idaho, Moscow.
- _____, and R. F. Thurow.
1974. Life history of St. Joe River cutthroat trout. Idaho Fish and Game Dept., Job Perf. Rept. F-60-R-5. 23 p.
- Boreman, J.
1974. Effects of stream improvement on juvenile rainbow trout in Cayuga Inlet, New York. Trans. Am. Fish. Soc. 103(3): 637-641.
- Burns, J. E.
1970. The importance of streamside vegetation to trout and salmon in British Columbia. Brit. Col. Fish and Wildl. Branch, Fish. Tech. Circ. 1. 12 p.
- Cordone, A. J.
1956. Effects of logging on fish production. Calif. Fish and Game Dept., Inland Fish. Admin. Rept. 56-7. 98 p.
- _____, and D. W. Kelley.
1961. The influence of inorganic sediments on the aquatic life of streams. Calif. Fish and Game 47:189-228.
- Corning, R. V., R. F. Raleigh, G. D. Schuder and A. Wood (ed.).
1975. Symposium on stream channel modification proceedings. Published by Stream channel modification symposium, Box 312, Grottoes, Vir. 172 p.
- Dunham, D. K., and A. Collotzi.
1975. The transect method of stream habitat inventory: guidelines and application. U.S. For. Ser. Intermt. Reg., Ogden, Utah. 98 p.
- Elser, A. A.
1968. Fish populations in a trout stream in relation to major habitat zones and channel alterations. Trans. Am. Fish. Soc. 97: 389-397.
- Gard, R.
1961. Creation of trout habitat by constructing small dams. Jour. Wildl. Mgmt. 25: 384-390.
- _____.
1972. Persistence of headwater check dams in a small stream. Jour. Wildl. Mgmt. 36:1363-1367.
- Gee, M. A.
1952. Fish stream improvement handbook. USDA Forest Service. 21 p.
- Gibbons, Dave R., and Ernest O. Salo.
1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA For. Serv. General Tech. Rep. PNW-10, 145 p. Pacific Northwest For. and Range Exp. Stn., Portland, Ore.
- Griffith, J. S.
1972. Comparative behavior and habitat utilization of brook trout (Salvelinus fontinalis) and cutthroat trout (Salmo clarki) in small streams in northern Idaho. Jour. Fish. Res. Bd. Canada 29:265-273.
- _____.
1974. Utilization of invertebrate drift by brook trout (Salvelinus fontinalis) and cutthroat trout (Salmo clarki) in small streams in Idaho. Trans. Am. Fish. Soc. 103:440-447.
- Grove, A. (ed.)
1976. Stream management of salmonids. Supplement to Trout Magazine, 17(1):31 p.
- Gunderson, D. R.
1968. Floodplain use related to stream morphology and fish populations. Jour. Wildl. Mgmt. 32:507-514.
- Herrington, R. B. and D. K. Dunham.
1967. A technique for sampling general fish habitat characteristics of streams. U. S. Forest Service, Intermountain For. and Range Exp. Sta., Res. Pap. 41. 12 p.
- Hogander, G., T. C. Bjornn and S. Pettit.
1974. Evaluation of catch-and-release regulations on cutthroat trout in the North Fork of the Clearwater River. Idaho Fish and Game Dept., Job Perf. Rept. F-59-R-5. 17 p.
- Hunt, R. L.
1966. Production and angler harvest of wild brook trout in Lawrence Creek, Wisconsin. Wisconsin Conserv. Dept., Tech. Bull. 35:52 p.
- _____.
1969. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wisconsin. In P. S. Larkin (ed.), Symposium on salmon and trout in streams. H. R. McMillan Lectures in Fisheries, Univ. of British Columbia, Vancouver. p. 281-312.

1970. A compendium of research on angling regulations for brook trout conducted at Lawrence Creek, Wisconsin. Wisc. Cons. Dept., Res. Rept. 54:37 p.
- Jackson, Bonnie J.
1974. Stream bed stabilization in Enfield Creek, New York. N. Y. Fish and Game Jour. 21:32-46.
- Jester, D. B. and H. J. McKirdy.
1966. Evaluation of trout stream improvements in New Mexico. Proc. West. Assoc. State Game and Fish Comm. 46:316-333.
- King, W. (ed.)
1975. Wild trout management. Trout Unlimited, Denver, Colo. 103 p.
- Klein, W. D.
1974. Special regulations and elimination of stocking: influence on fishermen and the trout population at the Cache la Poudre River, Colorado. Colo. Div. Wildl., Tech. Publ. 30:57 p.
- Latta, W. C.
1973. The effects of a flies-only regulation upon trout in the Pigeon River, Otsego County, Michigan. Mich. Dept. Nat. Res., Fish. Div., Fish. Res. Rept. 1807. 28 p.
- Little, R. G. and H. J. McKirdy.
1968. Statewide fisheries investigations. Rancho del Rio Grande grant, Carson National Forest. New Mexico Dept. Game and Fish. Job compl. rept. F-22-R-7 and F-22-R-8. 14 p.
- MacPhee, C.
1966. Influence of differential angling mortality and stream gradient on fish abundance in a trout-sculpin biotope. Trans. Am. Fish. Soc. 95:381-387.
- Marcuson, P.
1970. South-central Montana fisheries study. Rock Creek floodplain study. Montana Dept. of Fish and Game. Job Progr. Rept. F-20-R-14, Job IIa. 4 p.
- Megahan, W. F. and W. J. Kidd.
1972. Effects of logging and logging roads on erosion and sediment disposition from steep terrain. Jour. Forestry 80:136-141.
- Miller, R. R.
1972. Classification of the native trouts of Arizona with the description of a new species, Salmo apache. Copeia 3:401-422.
- Mullan, J. W.
1975. Fisheries habitat plan for the Uintah and Ouray Indian Reservation as affected by the Uinta and Opalco Units of the Central Utah Project. U. S. Fish and Wildlife Service, Salt Lake City, Utah. 132 p.
- Packer, P. E.
1957. Management of forest watersheds and improvement of fish habitat. Trans. Am. Fish. Soc. 87:392-397.
- Platts, W. S.
1974. Geomorphic and aquatic conditions influencing salmonids and stream classification. U. S. Forest Service, SEAM publication, Billings, Montana. 199 p. (mimeo.).
- Radford, D. S.
1975. The harvest of fish from Dutch Creek, a mountain stream open to angling on alternate years. Alberta Dept. of Recreation, Parks and Wildlife, Fish Mgmt. Rept. 15:54 p.
- Ringler, N. H. and J. D. Hall.
1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Trans. Am. Fish. Soc. 104:117-121.
- Schreck, C. B. and R. J. Behnke.
1971. Trout of the upper Kern River basin, California, with reference to systematics and evolution of western North American Salmo. Jour. Fish. Res. Bd. Canada 28: 987-998.
- Stalnaker, C. B., and J. L. Arnette (ed.)
1976. Methodologies for the determination of stream resource flow requirements. U.S. Fish and Wildlife Serv., Office of Biol. Serv., Western Water Allocation. 199 p.
- Sumner, F.
1940. The decline of the Pyramid Lake fishery. Trans. Am. Fish. Soc. 69:216-224.
- Trojnar, J. R. and R. J. Behnke.
1974. Management implications of ecological segregation between two introduced populations of cutthroat trout in a small Colorado lake. Trans. Amer. Fish. Soc. 103: 423-430.
- USDA Forest Service.
1975. Symposium on trout habitat research and management proceedings. USDA, USFS, Southeast For. Exp. Stn., Asheville, NC 110 p.

USDI Bureau of Land Management.

1974. Effects of livestock grazing on wildlife, watershed, recreation and other resource values in Nevada. Bureau of Land Management, Nevada State Office, Reno.

Webster, D. A. and G. S. Little.

1947. Angling experiments by the fly tyers' club at Cornell University. Trans. Am. Fish. Soc. 64:63-70.

Wesche, T. A.

1973. Parametric determination of minimum streamflow for trout. Water Resources Res. Inst., Univ. of Wyoming, Laramie. 102 p.

1974. Relationships of discharge reductions to available trout habitat for recommending suitable streamflow. Water Resources Res. Inst., Univ. of Wyoming, Laramie. 71 p.

White, R. J.

1973. Stream channel suitability for cold-water fish. Proc. 28th Ann. Mtg. Soil Cons. Serv. (Plants, Animals and Man): 61-79.

and D. M. Brynildson.

1967. Guidelines for management of trout stream habitat in Wisconsin. Wisc. Div. Cons., Tech. Bull. 39:65 p.



COLORADO RIVER CUTTHROAT
Salmo clarki pleuriticus

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral line)	170-200+
and above lateral line	
(origin of dorsal fin to lateral line)	38-48
Vertebrae	60-63
	(mean 61-62)
Gillrakers	17-21
Pyloric caecae	25-45
	(mean 30-40)
Basibranchial teeth	1-20

[Taxonomic data from Behnke (1974, 1975), Wernsman (1973)]

SPECIES DESCRIPTION

No meristic characters unique to S. c. pleuriticus exist which can serve to authoritatively assign a specimen to this taxon. Hybridization resulting from the introduction of rainbow trout and other subspecies of cutthroat trout into the Colorado River basin further complicates the recognition of pure populations. In general, the mean values of at least ten specimens are needed to determine the degree of purity of a population in question.

Salmo clarki pleuriticus, native to the upper Colorado River basin is, with the greenback trout of the Arkansas and South Platte drainages on the other side of the Continental Divide, among the most colorful of all the recognized forms of cutthroat trout. The highly variable coloration consists typically of a poorly defined pink or red band along the brassy yellow sides. The ventral region may be suffused with crimson in mature males.

Character variability between populations of differing geographical areas exists due to long physical isolation of major habitat areas in the Colorado and Green River basins. For example, cutthroat trouts native to the upper Green River basin (La Barge Creek, north) display small to moderate-sized spots, typically smaller than the pupil of the eye, concentrated mainly on the caudal peduncle and, anteriorly, above the lateral line. Significantly larger spots occur on cutthroats from the Little Snake River drainage (a tributary to the Yampa River); these may approach a size more typical of the greenback trout. All degrees of intermediacy in spotting occur, but one should expect pure or essentially pure populations to share a high degree of uniformity within any geographical area where they have had the opportunity to freely intercommunicate. Baxter and Simon (1970) and Baxter (1972) present photographs of the large-spotted form of the Colorado River cutthroat, probably taken of specimens from the Little Snake River drainage of Wyoming. The illustration in this report is based on a specimen from Rock Creek, Wyoming,



Map 1. Indigenous distribution of *Salmo clarki pleuriticus*.

and characterizes the spotting pattern of the native trout of the upper Green River system.

DISTRIBUTION

The original distribution of S. c. pleuriticus extended from the headwaters of the Colorado River basin downstream to the Dirty Devil River, Utah, on the west and to the San Juan drainage of Colorado, New Mexico and Arizona on the east. But due to the warmth and turbidity of the water, most areas of the Colorado and Green Rivers did not comprise trout habitat until after the construction of mainstream dams (Behnke 1974, Wernsman 1973). Resultant isolation of the various major tributaries caused much of the variability inherent in S. c. pleuriticus.

Only two populations of the many examined appear to be wholly pure. They occur in an isolated section of Rock Creek, tributary to La Barge Creek, and in North Beaver Creek, an isolated tributary in the Piney Creek drainage; both populations exist in Sublette County, Wyoming. A possibly pure population discovered in 1970 and described by Wernsman (1973) from the very headwaters of the Colorado River in Rocky Mountain National Park can probably now be considered extinct for all practical purposes. Extensive sampling of the area in 1974 and 1975 turned up only three cutthroat trout in a multitude of brook trout.

Numerous populations, however, remain phenotypically good representatives of S. c. pleuriticus even though they show some evidence of hybridization. Although coloration and spotting patterns remain typical, closer examination reveals a slight hybrid influence in the form of the absence of basibranchial teeth, a greater range of variability in meristic characters, and a shift in the mean values of some characters. Such populations, while not wholly pure, still merit special recognition in management and land use decisions affecting their well-being (Behnke 1974, 1975, 1976; Wernsman 1973).

STATUS AND POPULATION TREND

Although cutthroat trout exist in good numbers in small lakes and streams in the Colorado River basin of Colorado, Utah, and Wyoming, pure populations of S. c. pleuriticus are indeed rare throughout its range.

Habitat alteration and the introduction of non-native trouts have caused the precipitous decline of the Colorado River cutthroat. Brown trout and rainbow trout have completely replaced S. c. pleuriticus in larger rivers, and

brook trout have frequently displaced it in smaller tributaries, but the major factor pushing pure populations of the Colorado River cutthroat towards extinction has been hybridization with rainbow trout and non-native cutthroat trout used in stocking programs in Colorado, Utah, and Wyoming.

Miller (1972) included S. c. pleuriticus in his list of threatened freshwater fishes of the United States. The Utah Fish Committee of the American Fisheries Society's Bonneville Chapter lists it as endangered (Holden et al. 1974). The Colorado Division of Wildlife lists S. c. pleuriticus as threatened.

We recommend that S. c. pleuriticus be recognized as threatened by the U.S. Department of Interior.

LIFE HISTORY

No published life history data exist for this trout save that concerning the lacustrine-specialized and slightly hybridized population of Trapper's Lake, Colorado (Snyder and Tanner 1960, Drummond 1966), which has little value in relation to knowledge of the life history and ecology of S. c. pleuriticus throughout its range. All of the general information concerning life history and ecology appearing in Chapter I can be applied to S. c. pleuriticus.

A significant attribute of the Colorado River cutthroat in the Green River drainage of Wyoming lies in the fact that several "good" representative populations of this subspecies exist in several badly degraded streams of the foothills region. Many of these streams might be characterized as submarginal trout habitat, since they have suffered from the effects of overgrazing and irrigation dewatering, which have led in turn to erosion, warm temperatures and turbidity. In spite of habitat degradation and the introduction of rainbow trout and non-native forms of cutthroat trout, the native populations have resisted hybridization and displacement to a surprising degree. The only explanation appears to be that these local populations are hardy and adapted to the present conditions to such an extent that natural selection strongly favors maintenance of the native genotype. These factors--environmental degradation and the introduction of non-native

trouts--under which many predominantly S. c. pleuriticus still survive, have almost invariably caused the extermination of other subspecies of interior cutthroat trout (Behnke 1975).

HABITAT REQUIREMENTS AND LIMITING FACTORS

All western trouts of the genus Salmo possess essentially similar habitat requirements. A broad-based ecological variability allows populations to thrive in small streams, large rivers or lakes. While several lakes in the Colorado River basin originally contained S. c. pleuriticus whose basic life history attributes may have differed slightly from stream or river populations, the basic requirements in terms of temperature, oxygen, and substrate for reproduction and survival are quite similar for all S. c. pleuriticus. Any factors leading to loss of cover, siltation and warming of the waters will have detrimental impacts on cutthroat trout. But the most significant factor limiting the perpetuation of pure populations remains the hybridization resulting from the introduction of rainbow trout and exotic subspecies of cutthroat trout.

PROTECTIVE MEASURES

The Wyoming Game and Fish Department has hired a habitat management biologist, Dr. Allen Binns, to direct protection, enhancement and restoration of native trout populations in Wyoming. The Department is conducting several projects in the Green River drainage, some in cooperation with the Bureau of Land Management and the U. S. Forest Service. Projects include stream improvement, spawning enhancement, barrier construction, transplanting and experimental propagation. Dr. Binns reported on this work at the Colorado-Wyoming Chapter of the American Fisheries Society meeting in April 1975. Robert Behnke has examined several hundred specimens and has evaluated the relative purity of many samples of Green River basin cutthroat trout, collected during surveys made by Wyoming personnel (Behnke 1975).

The Bureau of Land Management, Colorado State Office, has fenced a section of Northwater Creek, a tributary to Parachute Creek in the oil shale country of northwest Colorado, to protect a good representative population of S. c. pleuriticus from livestock overgrazing. Another virtually pure population of S. c. pleuriticus occurs in Cunningham Creek, which has been affected by diversions from the Frying Pan-Arkansas Project of the Bureau of Reclamation. A cooperative agreement between the Colorado Division of Wildlife and the Bureau of Reclamation is designed to mitigate

the dewatering impact of the project on the trout population.

Another Bureau of Reclamation project, the Meek's Cabin Reservoir in the Utah-Wyoming border area, flooded a natural barrier on the Little West Fork of the Black Fork River and an artificial barrier was constructed to prevent hybridization of the essentially pure S. c. pleuriticus population with rainbow trout.

According to 1973 and 1974 annual reports on fisheries management in Rocky Mountain National Park, prepared by James Mullan of the U. S. Fish and Wildlife Service, Vernal, Utah, plans exist for reintroduction of S. c. pleuriticus into the Colorado River drainage in the Park.

RECOMMENDATIONS

Although the original range of S. c. pleuriticus covers a large area in Wyoming, Utah, Colorado and New Mexico, only in the Green River basin of Wyoming has a concerted effort been made to survey waters for native trout populations, evaluate their relative purity and institute protective and restorative measures. The efforts of the Wyoming Fish and Game Department should be emulated in Colorado, Utah and New Mexico in order to authoritatively determine its status and to develop programs to protect and perpetuate this trout throughout its range.

Populations which are virtually pure and judged to be good taxonomic representatives should be given special recognition in relation to habitat protection or enhancement projects.

Habitat improvement and transplants into barren or chemically treated streams and lakes can effect the increased abundance of pure populations. Habitat managers should consider special regulation fisheries programs both to offer anglers the opportunity to fish for a rare and beautiful native trout and to generate interest and support among the public for restoration programs.

These recommendations assume added significance in view of the fact that S. c. pleuriticus is native to all of the oil shale region and much of the potential coal strip mine areas of Colorado, Utah and Wyoming. A 1975 report prepared for the Office of Biological Services of the U. S. Fish and Wildlife Service (Thorne Ecological Institute, 1975), gave the highest research priority to threatened and endangered species.

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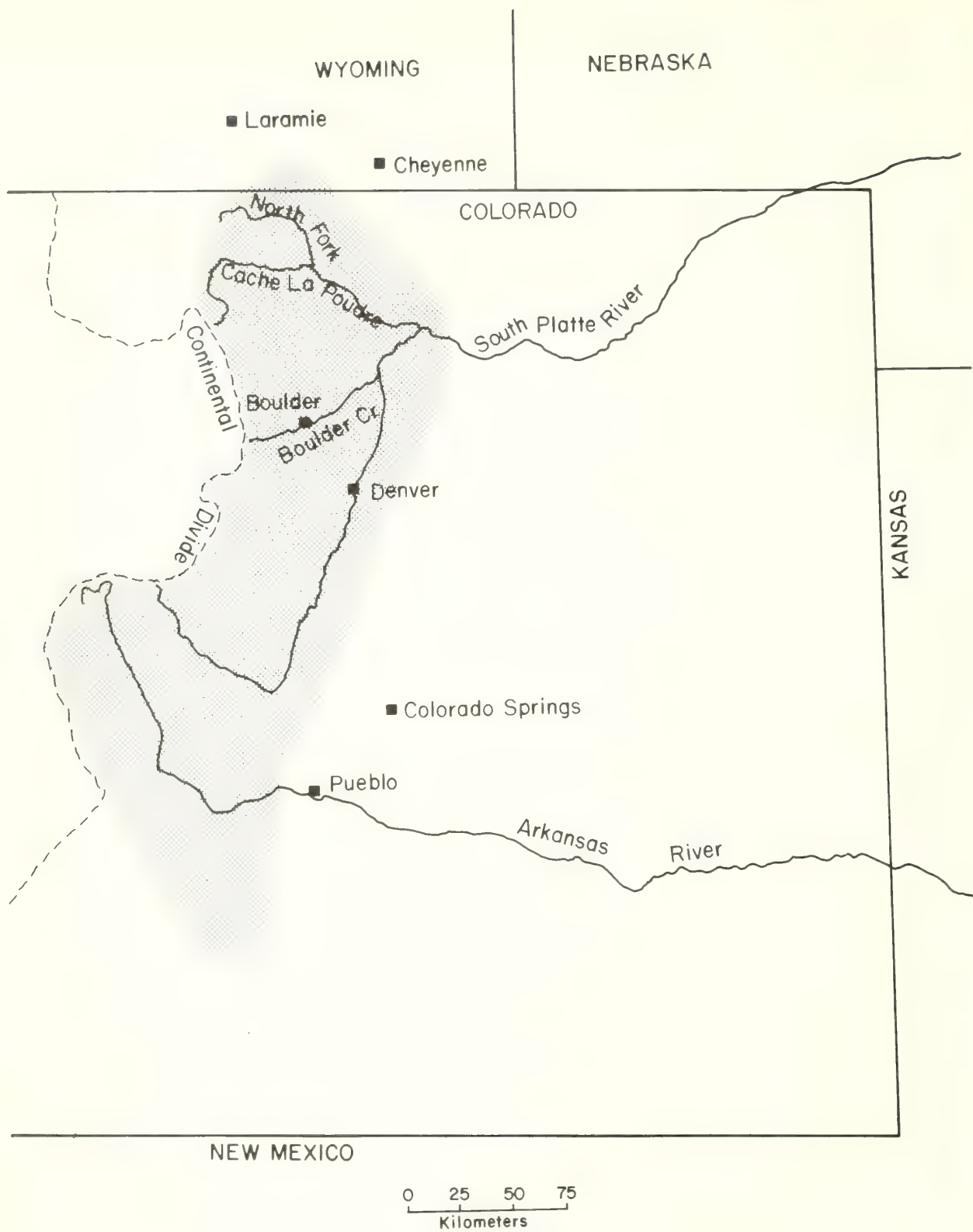
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REFERENCES

- Baxter, G. T.
1972. The cutthroat, a fish with native
roots. Wyo. Wildl. 36(5):16-19.
- _____ and J. R. Simon.
1970. Wyoming fishes. Wyoming Game and
Fish Dept., Bull. 4. 168 p.
- Behnke, R. J.
1970. Rare and endangered species report:
the native cutthroat trout of the Colorado-
Green River basin, Salmo clarki pleuriticus.
Colorado Cooperative Fishery Unit. 7 p.
(mimeo)
- _____.
1974. Status report: Salmo clarki
pleuriticus. Prepared for Region II,
U. S. Fish and Wildlife Service, Alberquer-
que, N.M. 6 p. (mimeo)

- _____.
1975. Report on recent collections of cut-
throat trout from the Green River basin,
Wyoming. Wyoming Game and Fish Department.
12 p. (mimeo)
- _____.
1976. Report on collections of cutthroat
trout from Parachute Creek drainage,
Garfield County, Colorado. Prepared for
BLM, Grand Junction. 7 p.
- Drummond, R. A.
1966. Reproduction and harvest of cutthroat
trout at Trapper's Lake, Colorado. Colo-
rado Department of Game, Fish and Parks,
Spec. Rept. 10:26 p.
- Holden, P. B., W. White, G. Somerville, D. Duff,
R. Gervais and S. Gloss.
1974. Threatened fish of Utah. Proc. Utah
Acad. Science, Arts and Letters 51 (pt. 2):
46-65.
- Miller, R. R.
1972. Threatened freshwater fishes of the
United States. Trans. Am. Fish. Soc.
101(2):239-252.
- Snyder, G. R. and H. A. Tanner.
1960. Cutthroat trout reproduction in the
inlets to Trapper's Lake. Colorado Dept.
of Game, Fish and Parks, Tech. Bull. 7:
86 p.
- Thorne Ecological Institute.
1975. Wildlife and oil shale, a problem
analysis and research program. U. S.
Fish and Wildlife Service, Office of
Biological Services. Vol. I. 112 p.
- Wernsman, G.
1973. The native trouts of Colorado. M.S.
Thesis, Colorado St. Univ., Ft. Collins.
57 p.



Map 2. Indigenous distribution of Salmo clarki stomias.



GREENBACK CUTTHROAT
Salmo clarki stomias

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral line)	175-220+
	(mean values 185-216)
and above lateral line	
(origin of dorsal fin to lateral line)	42-60
	(mean values 45-55)
Vertebrae	59-63
	(mean values 60-62)
Pyloric caecae	24-46
	(mean values 29-35)
Basibranchial teeth	Present, but highly variable

SPECIES DESCRIPTION

Taxonomic criteria for S. c. stomias remain tentative due to the extreme rareness of pure populations and to the scarcity of ancient museum specimens. Even so, scale counts made from available specimens consistently exhibit the highest values of any cutthroat trout, or any trout in the genus Salmo. It may be assumed that extremely high scale counts are characteristic of pure populations of S. c. stomias, with some suggestion that those populations native to the South Platte basin may show slightly higher counts than those native to the Arkansas drainage. The greenback cutthroat displays typically lower numbers of pyloric caecae and vertebrae than most other subspecies of S. clarki, but much overlap occurs in these characters.

Salmo clarki stomias undoubtedly derived via an ancient headwater transfer from waters of the Colorado River basin to the South Platte River drainage, and for this reason shares many similarities with the Colorado River cutthroat, S. c. pleuriticus. The striking spotting pattern and intense coloration which can develop in mature fish is the most diagnostic field character of the greenback trout. S. c. stomias typically displays the largest and most pronounced spots of any cutthroat trout. Round to oblong in shape, they appear concentrated posteriorly on the caudal peduncle area. Coloration, similar to S. c. pleuriticus, tends toward blood-red over the lower sides and ventral region, especially in

[Taxonomic data from Behnke (1973, 1976), Wernsman (1973)]

mature males. Although a genetic basis exists to express characteristic color patterns, the actual manifestation of color intensity and pattern depends also on age, sex and diet. For example, a lake environment with crustaceans available for food will induce a more intense expression of color than a small stream environment.

DISTRIBUTION

The original distribution of S. c. stomias included the headwaters of the South Platt and Arkansas River basins in Colorado and a small area in southeastern Wyoming, but permanent trout habitat did not extend much beyond the foothills region. The advent of white man's civilization rapidly pushed the greenback trout back to headwater areas, replacing it in the larger streams with brown trout, and with brook trout in smaller tributaries. Further introductions into headwater streams and lakes displaced or hybridized the native greenback trout to the point of virtual extinction.

STATUS AND POPULATION TREND

When the white man came to Colorado, the greenback trout was the only game fish found in the Arkansas and South Platte river systems of the state. Rapid development brought about irrigation diversions and stream dewatering, mining pollution, logging, grazing, widespread introduction of non-native trouts, and caused a precipitous decline of native trout populations. Greene (1937) believed they were extinct. Although cutthroat trout remain common in high elevation lakes and streams of the South Platte and Arkansas River basins, virtually none of the populations so far examined resemble the native greenback trout (Wernsman 1973) but instead have resulted from introductions of various non-native races and crosses of cutthroat trout, usually with traces of rainbow trout hybridization. This circumstantial evidence suggests that the greenback trout may be the most vulnerable of all the western trouts to extinction.

Analysis of all specimens examined to 1970 suggested only two pure populations. One of these occurs in Como Creek, an isolated tributary to North Boulder Creek, Boulder County, Colorado; the other is found in the very headwaters of the South Poudre River above a barrier falls in Larimer County, Colorado. Due to its extreme rareness, S. c. stomias has been listed as endangered by the U. S. Department of the Interior.

A more complete discussion on the status of the green back cutthroat was written by Behnke (1976).

LIFE HISTORY

Little specific life history data exist for the greenback cutthroat. While S. c. stomias appears to lack the resiliency and adaptability which it needs to coexist with introduced trouts, the mechanisms by which it is displaced in relation to spawning behavior, temperature, habitat and food preferences, or other factors, remain unknown.

Some life history data have been collected on two slightly hybridized populations which can be considered "good" representative greenback trout populations. Bulkley (1959) gathered information on age and growth, food habits and movement of the greenback population in the headwaters of the Big Thompson River in Forest Canyon of Rocky Mountain National Park. Nelson (1972) studied the unexploited population of Island Lake, a reservoir in the City of Boulder watershed, and provided data on age, growth and fecundity. Jordan (1891) and Juday (1907) made observations on size and food habits of greenback trout in Twin Lakes, Colorado. None of these reports indicate any unique life history attributes of S. c. stomias. That is, the data and observations are typical of any trout living under similar circumstances and offer little insight into whatever subtle differences in ecology exist for the greenback trout which make it so vulnerable to displacement and extinction.

Early literature (Jordan 1891, Juday 1907, Hallock 1877, Anon. 1878, Land 1913) indicates that S. c. stomias was originally abundant but not noted for its large size. It reached a maximum weight of about 2.3 kg; other subspecies of cutthroat trout were known to attain weights of 4.5 to 9 kg or more.

HABITAT REQUIREMENTS AND LIMITING FACTORS

While no factual evidence exists to specifically define greenback trout habitat requirements and limiting factors, circumstantial evidence suggests that all of those factors relating to habitat alteration and introduction of non-native trouts which have caused declines in other native interior trouts, have had a particularly debilitating effect on S. c. stomias. The most obvious factor preventing successful restoration of the greenback trout into its original habitat is the presence of non-native trouts. Certainly reintroduction programs for greenback trout cannot achieve success unless the proposed site is completely barren of all non-native trouts and thoroughly protected from re-invasion.

PROTECTIVE MEASURES

The U. S. Department of the Interior officially recognizes S. c. stomias as an endangered species.

In a cooperative venture undertaken by the U. S. Forest Service, the Colorado Cooperative Fishery Unit and the Colorado Division of Wildlife in 1967, construction of a fish barrier and elimination of the brook trout population above it created a sanctuary for the greenback trout in upper Black Hollow Creek, a tributary to the Poudre River in Larimer County, Colorado. A self-reproducing population of greenback trout was established by introducing adult greenbacks from Como Creek (Gagnon 1973). But in 1973, Dale Wills, U. S. Forest Service (personal communication to Robert Behnke), found two brook trout above the barrier. A survey conducted in August, 1975 by Rolf Nitman, Colorado Division of Wildlife, found the brook trout now to be the dominant trout in the creek.

Restoration efforts on a larger scale took place in October 1973 when brook trout were eliminated with antimycin above a natural barrier in Hidden Valley Creek, Rocky Mountain National Park. Complete eradication of brook trout from this creek was made especially difficult due to the presence of about 15 acres of beaver ponds and associated backwaters (Mullan 1973). A sampling of Hidden Valley Creek on August 27, 1975 by James Mullan, U. S. Fish and Wildlife Service, and Dave Stevens, U. S. National Park Service, found no brook trout, and documented the presence of adults from the 1973 transplant as well as fish from natural reproduction in 1974 and 1975. But another transplant of Como Creek trout into a barren headwater section of the North Big Thompson River in Rocky Mountain National Park in 1971 failed, evidently because all the fish migrated downstream over a barrier during the winter months. A dense brook trout population below the barrier makes it doubtful that the greenback population will sustain itself there. In October 1975 the National Park Service treated Bear Lake with antimycin to eliminate the brook trout population, and on November 4 introduced greenback cutthroat taken from Como Creek.

Other transplant programs have used virtually pure greenback populations. A 1959 transplant in Rocky Mountain National Park took greenback trout from the headwaters of the Big Thompson River in Forest Canyon and stocked them into Fay Lakes in the park. The population did not establish itself there, but descendants of the original introduction have maintained a self-reproducing population

in Caddis Lake, immediately below Fay Lakes, where James Mullan discovered them in 1972. Since 1971 the City of Boulder has granted permission to the Colorado Division of Wildlife to obtain spawn from a good representative greenback population in Island Lake and up to 100,000 eggs per year have been taken and propagated. The Division of Wildlife stocks these trout into several mountain lakes in northeastern Colorado as part of its fishery management program.

RECOMMENDATIONS

The greatest hope for expanding the distribution and abundance of S. c. stomias is by reintroducing it, within its native range, into suitable habitat barren of exotic trouts. Here, ironically, the 1973 Endangered Species Act actually hinders management of the greenback trout. While the intent of the Act is commendable, its prohibition of the "taking" or any form of harassment of an endangered species would mean closing to angling any stream into which greenback trout are introduced. Virtually all potential sites for greenback reintroduction are currently open to fishing. Public agencies are not enthusiastic to initiate restoration projects for an endangered trout which would result in closing public angling waters.

The simplest and most direct solution to this problem would be for the U. S. Department of the Interior to change the status of S. c. stomias from "endangered" to "threatened." A "threatened" status, while still affording protection under the Endangered Species Act, would not prohibit angling, thereby allowing this trout to be incorporated into fisheries management programs and encouraging the resumption of active restoration projects. This rare and beautiful trout has potential for inclusion in special regulation fisheries, which can stimulate public support for restoration programs, but first it must be removed from the endangered species list.

Well-organized surveys of isolated headwater areas of the South Platte and Arkansas River drainages could find and identify other pure or virtually pure greenback populations, as well as determine potential sites for reintroductions.

As with S. c. pleuriticus, it is not likely that many pure populations of S. c. stomias remain, but good representative populations, similar to those in Forest Canyon and Island Lake, should be identified for special recognition in relation to perpetuation and protection efforts.

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REFERENCES

Anonymous.

1978. Trout in the Rocky Mountains. Forest and Stream 9(25):468-469.

Behnke, R. J.

1973. The greenback cutthroat trout, Salmo clarki stomias. Status report prepared for U. S. Fish and Wildlife Service, Region II, Albuquerque, N. M. 11 p.

Behnke, R. J.

1976. Summary of information on the status of the greenback cutthroat trout, Salmo clarki stomias. Prepared for U.S. Fish and Wildlife Service, Salt Lake City Area Office. 30 p.

Bulkley, R. V.

1959. Report on 1958 fishing studies by the Bureau of Sport Fisheries and Wildlife in Rocky Mountain National Park. Rocky Mountain Sport Fisheries Investigations, Admin. Rept. 38 p.

Gagnon, J. G.

1973. The greenback. Trout 14(4):12-28, 30.

Greene, W. S.

1937. Colorado trout. Denver Mus. Nat. Hist., Popular Ser. 2. 48 p.

Hallock, C.

1877. The sportsman's gazeteer and general guide. New York. 688 p.

Johnson, J. E.

1976. Status of endangered and threatened fish species in Colorado. USDI, BLM, Tech. Note 280. 23 p.

Jordan, D. S.

1891. Report on explorations in Colorado and Utah during the summer of 1889, with an account of the fishes found in each river basin examined. Bull. U. S. Fish. Comm. 9:1-40.

Juday, C.

1907. A study of Twin Lakes, Colorado, with special consideration to the foods of the trouts. Bull. U. S. Bur. Fish. 26:147-178.

Land, S. E.

1913. The black-spotted mountain trout (Salmo stomias and related species). Trans. Am. Fish. Soc. 42:183-189.

Mullan, J. W.

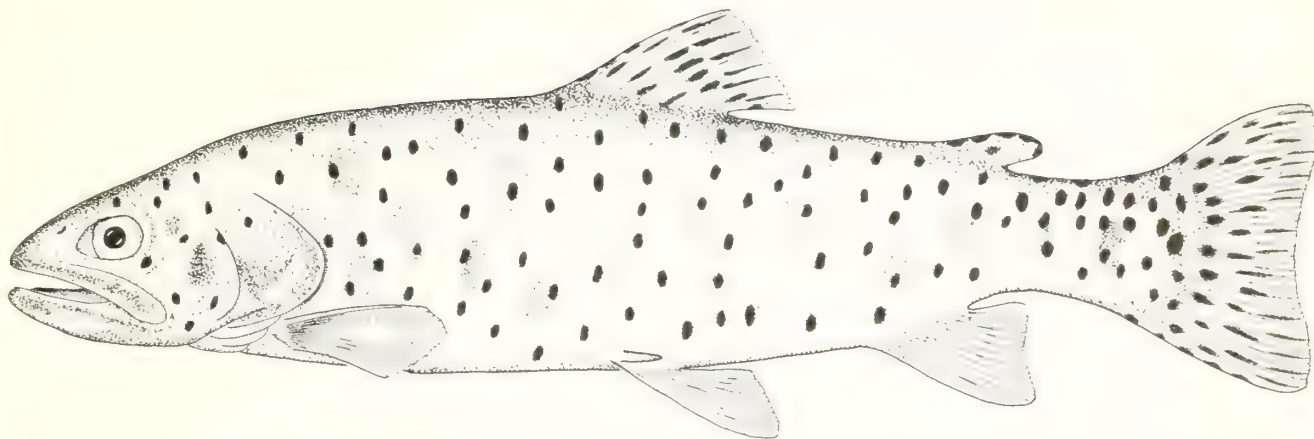
1973. Considerations in perpetuation of greenback cutthroat trout (Salmo clarki stomias). Spec. Rept. Fish. Mgmt. Program, Rocky Mountain Nat. Park. U. S. Fish and Wildlife Service, Vernal, Utah. 26 p.

Nelson, W. C.

1972. An unexploited population of greenback trout. Colo. Div. of Wildlife, Ft. Collins. 13 p. (mimeo)

Wernsman, G.

1973. Systematics of native Colorado trout. M. S. thesis, Colorado State Univ., Ft. Collins. 57 p.



LAHONTAN CUTTHROAT
Salmo clarki henshawi

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral line)	150-180
	(125-150) ^{a/}
and above lateral line	
(origin of dorsal fin to lateral line)	33-42
Vertebrae	61-63
Gillrakers	21-28
	(19-23) ^{a/}
Pyloric caecae	40-75+
Basibranchial teeth	Numerous and well developed

SPECIES DESCRIPTION

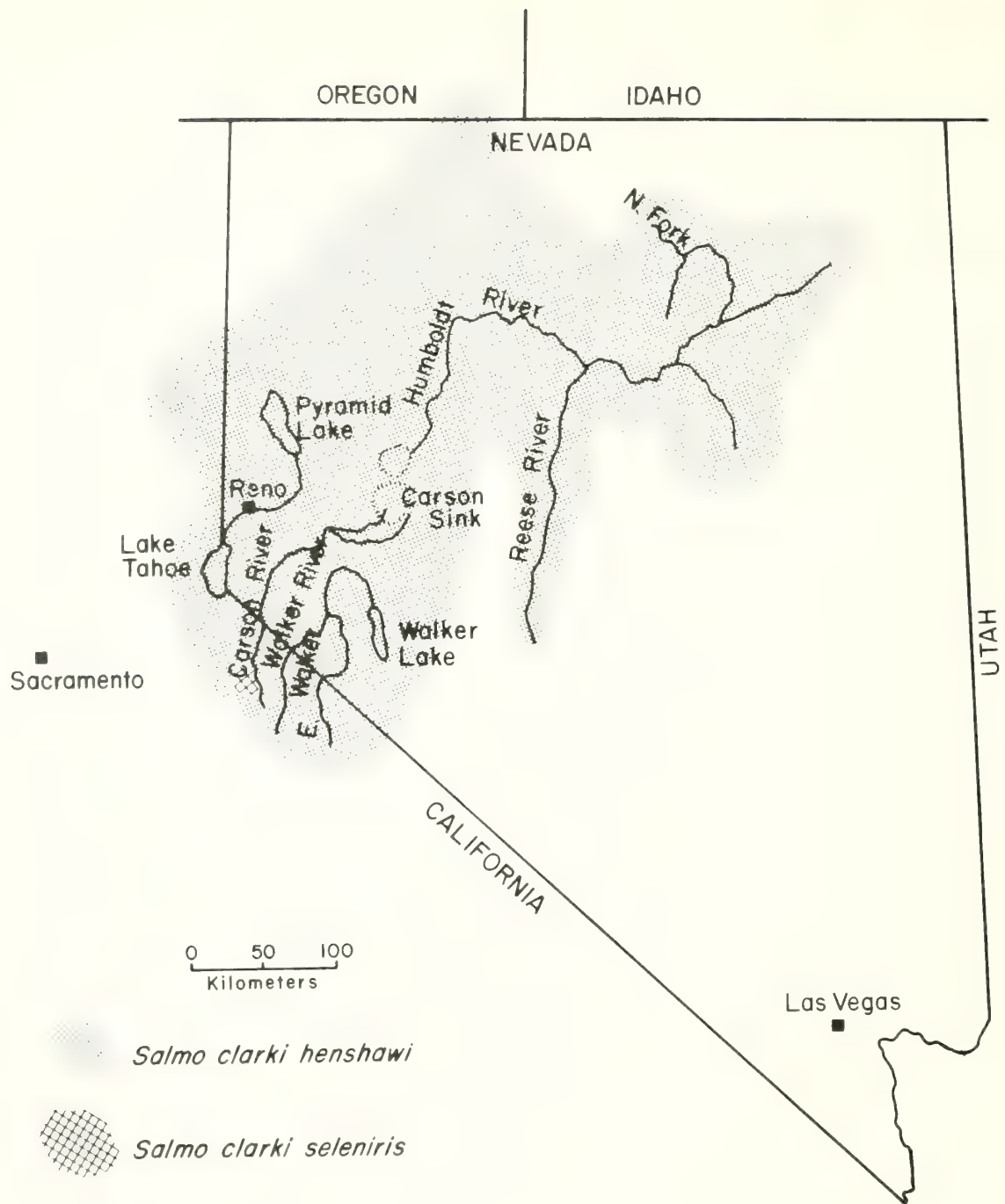
The Lahontan cutthroat trout achieved its great differentiation from all other subspecies of Salmo clarki due to its long physical isolation in the Lahontan basin with the resultant evolutionary selection for lacustrine specialization in pluvial Lake Lahontan, once the size of present-day Lake Erie. The number of gillrakers, higher than in any other western North American trout, further substantiates the ancient lacustrine evolutionary heritage of S. c. henshawi; with few exceptions, other taxa of trout possess only 17-21 gillrakers.

^a Typical values of trout native to the Humboldt River system of Nevada.

The number of pyloric caecae is also higher in the Lahontan cutthroat than in other subspecies of S. clarki.

When Lake Lahontan desiccated 5000 to 8000 years ago, the separation of its major tributaries effectively isolated the fish fauna of the Carson, Walker, Truckee and Humboldt river systems from each other. One would expect a high degree of genetic variability among the populations of the different drainages under such circumstances, but in fact, all specimens examined from pure populations in the Truckee, Carson and Walker drainages conform to the diagnosis given above (Behnke 1960). However, the native cutthroat of the Humboldt River system of Nevada differentiates recognizably from cutthroats in the other tributaries to ancient Lake Lahontan. It displays fewer scales in the lateral series and a lower number of gillrakers. The Humboldt cutthroat trout may represent an undescribed subspecies which probably separated from S. c. henshawi much earlier than the final desiccation of Lake Lahontan, and probably differentiated in response to evolutionary stimuli to adapt to fluvial conditions in order to utilize the vast Humboldt River system (Behnke 1960, 1968, 1972b).

Jordan and Evermann (1898) described Salmo clarki tahoensis from Lake Tahoe under the assumption that two different cutthroat trouts, differentiated by size, inhabited Lake Tahoe. However, the type



Map 3. Indigenous distribution of Salmo clarki henshawi and Salmo clarki seleniris

specimen of S. c. tahoensis is identical to S. c. henshawi and the observed size difference probably resulted from the presence of both older fish which had repeatedly spawned, and younger fish spawning for the first time, in the spawning runs. Behnke (1960) considers S. c. tahoensis a synonym of S. c. henshawi. Salmo evermanni, a name also used to describe S. c. henshawi, was based on an introduced population of Lahontan cutthroats in the upper Santa Ana River, California (Benson and Behnke 1961). The trout named Salmo regalis from Lake Tahoe, and S. smaragdus from Pyramid Lake, are considered to be based on introduced rainbow trout, S. gairdneri (Behnke 1972c).

Thus, a primordial cutthroat invaded the Lahontan basin, probably from the Columbia River basin, and gave rise to a large lacustrine predatory fish, S. c. henshawi, from which an early separation led to the development of the cutthroat trout endemic to the Humboldt River drainage. Except for populations inhabiting Lake Tahoe, Pyramid Lake, Walker Lake and a few smaller lakes, the Lahontan cutthroat was forced to become a stream trout by the desiccation of Lake Lahontan. This ultimate division between lake and stream populations, with its associated evolutionary programming, did not result in taxonomic differentiation (except for that exhibited by the Humboldt cutthroat), but it is significant for subsequent discussions concerning life history, habitat, and the reasons for the catastrophic declines in abundance suffered by this trout.

The spotting pattern of the Lahontan cutthroat constitutes its most diagnostic field character. Large, roundish spots cover the body evenly and extend onto the head and often to the ventral surface. Other subspecies of interior cutthroat trout typically lack spots on the head and ventral region, and have spots more concentrated posteriorly on the caudal peduncle area. Coloration of the Lahontan cutthroat is dull when compared with that of the Colorado River cutthroat or the greenback trout. The crimson, gold and orange colors, if present at all, are much subdued.

DISTRIBUTION

The Lahontan cutthroat trout at one time occurred in abundance throughout the Lahontan Basin of California and Nevada, with major lacustrine populations in Pyramid Lake, Walker Lake, Independence Lake and Lake Tahoe, California, and Summit Lake, Nevada; fluvial populations occurred in the Carson, Walker and Truckee River systems of California and in the Humboldt drainage of Nevada.

Currently the only lakes which harbor pure stocks of S. c. henshawi are Summit Lake, Nevada, and Independence Lake, California. By 1959 the only other known populations conforming to the diagnosis of S. c. henshawi occurred in Dog Creek of the Walker River drainage of California, the very headwaters of the East Carson River above a falls, and one of its tributaries, Murray Canyon Creek (Behnke 1960). Behnke discovered a small, apparently pure population in Pole Creek, tributary to the Truckee River, in 1961, but ten years later extensive electro-fishing disclosed only brook trout, and the native cutthroat of Pole Creek is now presumed extinct. More recently, apparently pure S. c. henshawi populations have been discovered in Golden Canyon Creek (an East Carson River tributary), By-Day Creek and East Fork Desert Creek (in the Walker River drainage), and Macklin Creek (tributary to the Yuba River in the Sacramento River basin). The Macklin Creek population is probably the result of an early transplant from the Truckee River. A transplant from Macklin Creek into a barren, isolated section of East Fork Creek of the Yuba River drainage in 1970 and 1971 has established a small population there (California Department of Fish and Game, Threatened Trout Committee notes; Stephen Nicola, personal communication to R. Behnke).

Both California and Nevada annually propagate millions of "S. c. henshawi", but the great majority of these hatchery fish come from the Heenan Lake stock which originated from a transplant of S. c. henshawi from the Carson River--a fluvial, not a lacustrine population--into Blue Lake, California, in 1864. Two subsequent introductions of rainbow trout into Blue Lake resulted in hybridization before the establishment of the present stock in Heenan Lake. The Heenan Lake "cutthroat" bears a good phenotypic resemblance to S. c. henshawi, but the lower number of scales and gillrakers (Behnke 1960) and the makeup of its blood serum (Utter and Ridgway 1966) disclose the rainbow trout influence. Thus, the trout widely propagated as S. c. henshawi is in reality a counterfeit of the real thing, and the widespread introduction of the Heenan Lake stock in California and Nevada is not considered as part of the distribution of the true S. c. henshawi.

STATUS AND POPULATION TREND

Commercial fisheries harvested vast numbers of Lahontan cutthroat trout, famed for its abundance and size, from Pyramid Lake, Walker Lake and Lake Tahoe during the last half of the nineteenth century, supplying the needs of towns and mining camps in the area

and shipping surplus fish by Wells Fargo express to San Francisco and other cities. Robert Behnke, in a 1974 report prepared for the Paiute tribe's litigation over the water rights and fishery values of Pyramid Lake, conservatively estimated that the cutthroat trout of Pyramid Lake alone could have supported a fishery of 454,000 kg per year in the nineteenth century. And yet the famed Pyramid Lake cutthroat stock was allowed to become extinct in 1938 (Sumner 1940) despite the fact that it was the largest of all western trouts; the average size of fish caught in 1938 was nine kg (Sumner 1940), and even though the official record for this trout (and the world record cutthroat trout) was 18.6 kg, the Indian fishery at Pyramid Lake reported trout weighing up to 28 kg (Wheeler 1969).

Fish commission reports of Nevada and California and other early literature condemned rampant poaching, uncontrolled exploitation and damming, diversion and pollution of the rivers. But overfishing did not bring about the virtual demise of S. c. henshawi. Blockage of spawning tributaries decimated the lacustrine populations, and the introduction of non-native trouts into the streams of the Lahontan basin caused replacement or hybridization of the native cutthroat trout in the rivers.

It may seem strange that such a large trout, once so abundantly distributed throughout the great area of the Lahontan basin could so rapidly slide toward extinction. The populations inhabiting Pyramid, Tahoe and Walker Lakes were specialized to exist in a lacustrine habitat; they had adapted very highly to their environment. These stocks appeared greatly resistant to the effects of hybridization, perhaps through negative selection toward any hybrids produced. The original cutthroat trout of Pyramid Lake and Lake Tahoe maintained their stocks until the 1930's, despite massive stocking of rainbow trout into the lakes and tributaries since before 1890, and deliberate experimental hybridization in hatchery propagation (Behnke 1960). But in 1906, the Newlands Irrigation project constructed Derby Dam on the Truckee River, 30 miles above Pyramid Lake. Thus, the Pyramid Lake cutthroat trout were denied access to most of the spawning habitat of the Truckee River (Snyder 1917). Even so, these trout were to maintain their numbers until the 1920's, when diversion of the entire flow of the Truckee became more frequent, with consequent great losses of spawning trout. The last spawning run of trout in the Truckee River occurred in 1938 (Sumner 1940), but streamflow was insufficient for reproductive success and this magnificent

race became extinct. In Lake Tahoe, damming, pollution and siltation of its tributaries resulted in the demise of the native cutthroat soon thereafter. The cutthroat trout of Walker Lake held on until 1948 when 16 large spawners were trapped near the mouth of the Walker River, which, due to irrigation diversions, no longer had flows sufficient for the reproductive requirements of the trout in the lake. The Nevada Department of Fish and Game removed spawn from these trout and began a brood stock; the present population of Walker Lake is maintained by hatchery propagation (Behnke 1960, Johnson 1974).

S. c. henshawi possessed an evolutionary heritage which made it highly adapted and successful in lake environments; it was much less suited for stream existence and quite vulnerable, in fluvial environments, to displacement by brook, brown and rainbow trouts and to hybridization with rainbow and non-native cutthroat trouts. Today only a very few streams shelter pure stocks of Lahontan cutthroat trout (see page 22).

The purity of the Walker Lake stock, propagated in Nevada, is in doubt. No ancient museum specimens exist for study of the original population, and ample opportunity for hybridization in the Walker River has existed for more than half a century. Indeed, specimens of the stock raised at Verdi, Nevada, have slightly lower gillraker counts and scale counts than is typical of pure S. c. henshawi (Behnke 1960). But the highly alkaline Walker Lake environment, lethal to all other trouts, probably exerted selective pressures strong enough to maintain the genotype of the Walker Lake cutthroat without significant modification from hybridization. The cutthroat trout of Walker Lake may play an increasingly significant role in propagation efforts involving a large, lacustrine predator. Cutthroat trouts of Walker and Independence Lakes are the only existing stocks that have historically coexisted with other elements of the native fish fauna of the Lahontan basin and as such might be expected to possess the genetic programming for maximizing effective coexistence with and utilization of this associated fauna in other lakes.

The native cutthroat trout of the Humboldt River drainage of the Lahontan Basin of Nevada has fared better than S. c. henshawi in the rest of the basin. This trout, evidently more specialized for stream life and apparently highly adapted to the harsh flood-drought cycle of this arid region, has persisted in many small streams despite repeated introductions of non-native trouts. Pure or essentially pure populations exist in about 20 streams

(R. J. Behnke, personal notes and data). The entire trout populations in some small streams may be restricted to a few small pools and beaver ponds in late summer, when the streams become intermittent. Although the undescribed subspecies of the Humboldt drainage persists in several localities, it cannot be considered as common or abundant, and merits the same considerations for protection and restoration as S. c. henshawi.

Bond (1961, 1966) listed S. c. henshawi as the native trout of the Alvord desiccating basin, which is contiguous with the northern Lahontan basin on the Oregon-Nevada border. Behnke (1960) recognized that there were two distinct groups of cutthroat trout in this basin (or basins), one in the Virgin Creek - Trout Creek drainage of the Alvord Lake sump and one in Willow and Whitehorse Creeks, which drain out onto the desert east of Alvord Lake at a higher elevation. At that time Behnke believed that the trout collected from Virgin Creek, which possessed 21-25 gillrakers, were probably introduced Lahontan cutthroat trout and that the Willow and Whitehorse Creek populations constituted an undescribed subspecies. Subsequent information and re-examination of the Virgin Creek specimens has caused Behnke to reject his previous belief that these specimens are S. c. henshawi. Though the Lahontan cutthroat may have gained access to Virgin Creek and the Alvord basin via an ancient connection with Summit Lake, the specimens are sufficiently dissimilar to be classified as a new subspecies (Behnke 1972b, 1973). The native trout of the Virgin Creek - Trout Creek drainage of the Alvord basin of Nevada and Oregon are presumed extinct, since no specimens have been collected since 1934. The characteristics of the cutthroat trout in Willow and Whitehorse Creeks are close to the Humboldt cutthroat of the Lahontan basin and their origin may have resulted from a headwater stream capture from the Humboldt system. Native trout still exist in Willow and Whitehorse Creeks but remain unclassified.

Due to the extreme rareness of pure S. c. henshawi, the U. S. Department of the Interior endowed it with the status of "endangered." But to facilitate management and restoration efforts, the status of the Lahontan cutthroat trout was changed from "endangered" to "threatened" (Federal Register 40(137), 16 July 1975). This action also avoided the problem of attempting to enforce the "no taking" provision of the Endangered Species Act of 1973 in the popular sport fishery at Pyramid Lake, where pure S. c. henshawi from Summit Lake, partially hybridized S. c. henshawi from the Heenan Lake stock and F₁ rainbow x cutthroat hybrids have all been stocked together to provide angling.

LIFE HISTORY

Snyder (1917) made many general observations relating to life history of Lahontan cutthroat trout, mainly the Pyramid Lake stock. Juday (1907) published some data on Lake Tahoe cutthroat. Calhoun (1944a, 1944b) described some life history attributes of the partially hybridized Heenan Lake trout in Blue Lake and Heenan Lake. Lea's (1968) M. A. thesis on the Independence Lake cutthroat contains the most comprehensive data on a pure population of S. c. henshawi.

All of the above studies were based on lacustrine stocks. The work of Calhoun (1944a), which points out the variability in growth, age at maturity, food habits and other life history factors between populations of the same stock (the Heenan Lake strain) living in Blue Lake and in Heenan Lake demonstrates that the specific details gained from any life history study must be restricted in application to the site of the studies. Broad generalizations applied to other populations might prove erroneous.

Based on all these studies, particularly that of Lea (1968), it may be assumed that in lakes, S. c. henshawi tends to feed more in the pelagic zones and on the surface. When available, fish become predominant in its diet when it reaches a size of about 30.5 cm. In Independence Lake, the reidside shiner, kokanee salmon and Paiute sculpin were the main fish eaten.

The geologic history of the Lahontan basin and the distinctive characters of S. c. henshawi indicate that this trout has had the longest period of evolution of any western trout in which to specialize as a large predator in a lacustrine environment (Behnke 1972c).

The weak link in the life cycle of S. c. henshawi concerns its reproductive requirements; it is an obligatory stream spawner. The subspecies' superb adaptability to the Truckee River - Pyramid Lake system was negated by the blockage of access to spawning habitat in the Truckee River.

S. c. henshawi well illustrates certain ideas regarding intraspecific variability in ecological, physiological, and behavioral traits. The various stocks, isolated thousands of years ago by the desiccation of Lake Lahontan, were subjected to their own unique genetic programming under natural selection in different environments, and this was particularly true in lacustrine versus fluvial populations. Probably only the Pyramid Lake population of S. c. henshawi continuously

evolved in a large lake environment with a full range of the Lahontan basin fauna.

Interpretation of this evidence suggests that no existing trout classified as S. c. henshawi, introduced into Pyramid Lake, can be expected to duplicate the adaptive success and large size of the original Pyramid Lake S. c. henshawi, due to subtle differences in their life history characteristics. This interpretation is supported by the fact that in almost two decades of stocking "S. c. henshawi" into Pyramid Lake, the maximum size recorded has not reached the average size of the original stock recorded during its 1938 spawning run, and only reaches one-third to one-half the maximum size once attained by the now-extinct Pyramid Lake cutthroat (Behnke 1968, 1972a, 1972c; Trojnar and Behnke 1974).

HABITAT REQUIREMENTS AND LIMITING FACTORS

The lack of suitable stream spawning habitat has limited lacustrine populations of S. c. henshawi. Although hatchery propagation and stocking into lakes provide a means of avoiding this limiting factor, until brood stocks of S. c. henshawi are greatly expanded, the introduction of S. c. henshawi x S. gairdneri hybrids cannot be considered an authentic restoration of the Lahontan cutthroat.

Stream populations of Lahontan cutthroat have suffered from hybridization with rainbow trout, except in the Humboldt River basin. Many of the streams in which the Humboldt cutthroat occurs have a long history of stocking with rainbow trout, Yellowstone cutthroat, and brook and brown trout. The only reasonable explanation for the resistance of the Humboldt cutthroat to displacement and hybridization might be this trout's superior adaptation to its harsh environment.

A unique tolerance to high alkalinity levels, which can be attributed to a physiological adaptation to the environments of Lake Lahontan during its period of desiccation and increasing concentrations of dissolved solids, allows S. c. henshawi (or trout with a predominant S. c. henshawi genotype) to thrive in waters such as Walker Lake which are lethal to all other trouts (Johnson 1974). The mechanisms of "alkalinity toxicity" and precisely which ions are toxic to other trouts, yet tolerated by S. c. henshawi, remain unknown. But this unique adaptation to an environmental extreme by S. c. henshawi could prove useful in establishing fisheries in lakes where other trouts could not survive.

PROTECTIVE MEASURES

The Threatened Trout Committee of the California Department of Fish and Game has conducted surveys to find remnant populations of S. c. henshawi and to determine sites for establishment of new populations by transplants. A successful transplant of this subspecies from Macklin Creek to the barren headwaters of nearby East Fork Creek took place in 1970 and 1971. Propagation of Independence Lake cutthroat began primarily to maintain the stock in Independence Lake; 32,000 trout from eggs taken in 1974 were on hand in 1975. Of these, 5000 were marked and stocked in Heenan Lake to facilitate future propagation and 25,000 were restocked into Independence Lake (Threatened Trout Committee, California Department of Fish and Game minutes of meetings; Stephen Nicola, personal communication to Robert Behnke). Removal of the beaver dams which blocked the spawning run from Independence Lake in 1964 greatly increased the success of natural reproduction of this stock (Lea 1968).

The impact and potential threat to the Independence Lake cutthroat stock by the planned Walt Disney Productions resort to be built at Independence Lake, is difficult to forecast. The obvious threat of eutrophication exists, but more important might be a demand for stocking great numbers of trout to meet increased fishing pressure in Independence Lake. Hopefully, developers will recognize the uniqueness and value of the native Lahontan cutthroat of Independence Lake and design a propagation program and special regulation fishery based on this fish and perhaps kokanee salmon.

The U. S. Fish and Wildlife Service propagates the pure strain of S. c. henshawi in Summit Lake with the objective of restoring it in Pyramid Lake. The ultimate goal is to re-establish natural reproduction in the Truckee River, once adequate flows and fish passage facilities become a reality in the lower Truckee River (Gary Rankel, U. S. Fish and Wildlife Service, personal communication to Robert Behnke). But as noble as this goal may be, present conditions in the Truckee, particularly the potential for hybridization with the abundant rainbow trout population which exists there, indicates that its realization will be difficult if not impossible.

In recognition of the significance of the Mahogany Creek watershed, the only spawning tributary available to the Summit Lake cutthroat stock, the Bureau of Land Management removed the watershed from mining exploration to protect this stream from further degradation. But it failed to institute the grazing controls

which had been proposed, and consequent effects of overgrazing resulted in the need to remove silt buildup at the mouth of the stream each year to allow the spawning trout to enter the stream. The BLM cited the effects of livestock grazing on the Summit Lake cutthroat in its environmental impact statement on grazing in Nevada (Anonymous 1974) as an example of the problems of multiple-use management on public lands when livestock interests wield the predominant influence--despite national priorities regarding the survival of an endangered species.

In the Humboldt drainage, a successful transplant of the native trout from Frazer Creek to Sherman Creek, Elko County, Nevada has taken place, with future transplants anticipated. The new Sherman Creek population has been observed in water temperatures reaching 25.6° C., perhaps a record high temperature for cutthroat trout in natural conditions (Pat Coffin, Nevada Fish and Game Department, personal communication to Robert Behnke).

RECOMMENDATIONS

The importance of the Lahontan cutthroat trout both in propagation as a sport fish and for the role it plays in fisheries management dictates two goals for the management and restoration of this trout:

1. Identification, protection and transplants of pure population

2. Propagation of pure S. c. henshawi to replace the hybridized Heenan Lake strain for stocking in the Lahontan basin.

Some compromises might be encouraged in selection of stocks in order to create the best-adapted genotype for waters such as Pyramid Lake. The Summit Lake population, the major pure stock of S. c. henshawi available for propagation, has probably been isolated from all other fishes for several thousand years. Crossings of the Summit Lake trout with Independence Lake cutthroat and/or Walker Lake cutthroat might result in a broader base of heterozygosity and greater adaptability to new waters. Because virtually all introductions of hatchery-propagated S. c. henshawi occur in lakes where natural reproduction does not occur, no negative impact would be expected from experimental interracial hybridization in a restoration program for pure S. c. henshawi. Of course, the only trout stocked into Independence Lake, where natural reproduction does occur, should be from the native population.

One promising option of a propagation program should be tested and that concerns the propagation from parents surviving in the new environment to take advantage of natural selection favoring certain hereditary traits. For example, the stocking of Summit Lake cutthroat trout into Pyramid Lake is presently accomplished by an annual egg take at Summit Lake so that each generation in Pyramid Lake is derived directly from Summit Lake. A comparison should be made over several generations in relation to survival and contribution to the Pyramid Lake fishery, between fish propagated from eggs taken at Summit Lake and from eggs taken from Summit Lake trout surviving to maturity in Pyramid Lake. An item in the Sport Fishing Institute Bulletin (April, 1976) is of particular relevance in this respect. A race of Columbia River coho salmon stocked in the Lamprey River, New Hampshire, gave a total survival of adults returning to the home stream of 1.22 percent, but the F_1 generation resulting from eggs taken from the returning salmon yielded a total survival of 5.75 percent or a 4.7 fold increase in survival and also a 50 percent increase in average weight of surviving salmon.

The Walker Lake strain needs an evaluation of its relative purity. The Humboldt native cutthroat needs an established lake, similar to Heenan Lake, for its propagation. This trout possesses a good fisheries management potential, acquired during its recent evolution under the harsh climatic regime of northeastern Nevada. When it has gained access to reservoirs from its headwater strongholds during high runoff years, the Humboldt cutthroat has greatly exceeded hatchery trout in both growth and survival (Behnke 1968 and personal data).

A propagation program for S. c. henshawi and the Humboldt cutthroat should have as one of its goals that of demonstrating the practical values of preserving and utilizing the genetic diversity of rare and endangered trouts to again make these fish a dominant element in their native range.

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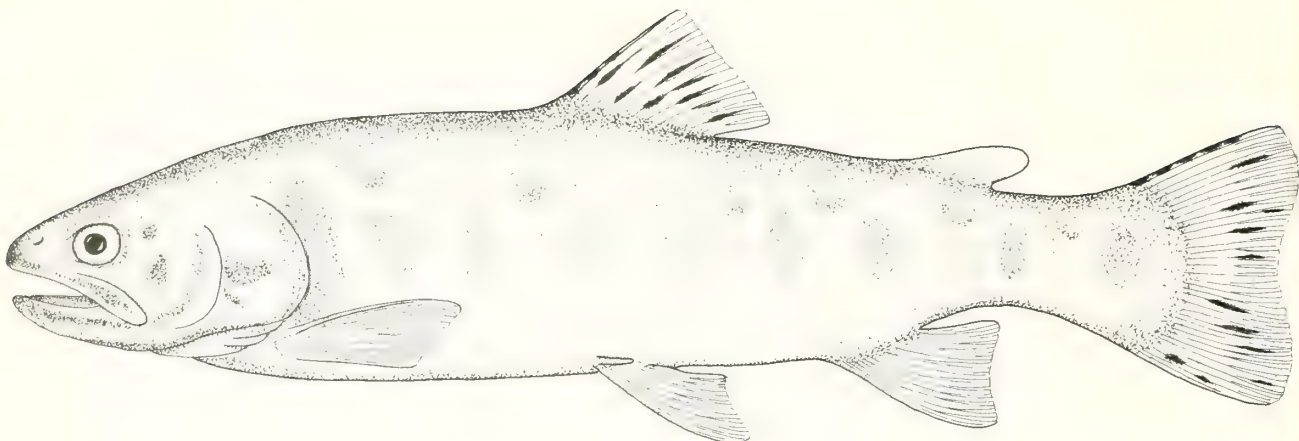
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REFERENCES

- Anonymous.
1974. Effects of livestock grazing on wild-
life, watershed, recreation and other re-
source values in Nevada. Bureau of Land
Management, Nevada State Office, Reno.
- Behnke, R. J.
1960. Taxonomy of the cutthroat trout of
the Great Basin with notes on the rainbow
series. M. A. Thesis, Univ. of California,
Berkeley. 98 p.
-
1968. Rare and endangered species: the
native trouts of western North America.
Proc. West. Assoc. State Game and Fish
Comm. 48:533-535.
-
- 1972a. The rationale of preserving genetic
diversity: examples of the utilization of
intraspecific races of salmonid fishes in
fisheries management. Proc. West. Assoc.
State Game and Fish Comm. 52:559-561.
-
- 1972b. Rare and endangered trouts of the
Southwest. In Symp. on Rare and Endan-
gered Wildlife of the Southwestern United
States. New Mexico Department of Game
and Fish, Santa Fe. p. 129-133.
-
- 1972c. The systematics of salmonid fishes
of recently glaciated lakes. Jour. Fish.
Res. Bd. Canada 29(6):639-671.
- Benson, S. B. and R. J. Behnke.
1961. Salmo evermanni a synonym of Salmo
clarki henshawi. Calif. Fish and Game
47(3):257-259.
- Bond, C. E.
1961. Keys to Oregon freshwater fishes.
Agric. Exp. Sta., Oregon State Univ.,
Corvallis. Tech. Bull. 58. 42 p.
-
1966. Endangered plants and animals of
Oregon, Vol. I. Fishes. Agric. Exp. Sta.,
Oregon State Univ., Corvallis. Spec. Re-
port 205. 8 p.
- Calhoun, A. J.
1944a. The food of the black-spotted trout
in two Sierra Nevada lakes. Calif. Fish
and Game 30(2):80-85.
-
- 1944b. Black-spotted trout in Blue Lake,
California. Calif. Fish and Game 30(1):
22-42.
- California Department of Fish and Game.
1965. Species plans: Lahontan cutthroat
trout. In California Fish and Wildlife
Plan, Calif. Dept. of Fish and Game,
Sacramento. Vol. II:119, 147.
- Johnson, K.
1974. Angler's guide to Walker Lake.
Nevada Outdoors and Wildlife Review 8(1):
15-18.
- Jordan, D. S. and B. W. Evermann.
1898. The fishes of North and Middle America.
Bull. U. S. Nat. Mus. 47 (pt. 3):2184-3136.
- Juday, C.
1907. Notes on Lake Tahoe, its trout and
trout fishing. Bull. U. S. Bur. Fish.
26:133-146.
- LaRivers, I.
1962. Fishes and fisheries of Nevada. Nev.
Fish and Game Comm., Reno. 782 p.
- Lea, R. N.
1968. Ecology of the Lahontan cutthroat
trout, Salmo clarki henshawi, in Inde-
pendence Lake, California. M. A. Thesis,
Univ. of California, Berkeley. 95 p.

- McAfee, W. R.
1966. Lahontan cutthroat trout. In A. J. Calhoun (ed.), Inland Fisheries Management. Calif. Dept. of Fish and Game, Sacramento. p. 225-231.
- Rankel, G. L.
1976. Fishery management program, Summit Lake Indian Reservation, Humboldt County, Nevada. U.S. Fish and Wildlife Serv., Div. Fish Services, Reno, Nevada, Special Rep. 35 p.
- Snyder, J. O.
1917. Fishes of the Lahontan system of Nevada and northeastern California. Bull. U. S. Bur. Fish. 35:31-86.
- Sumner, F. H.
1940. The decline of the Pyramid Lake fishery. Trans. Amer. Fish. Soc. 69:216-224.
- Trojnar, J. R. and R. J. Behnke.
1974. Management implications of ecological segregation between two introduced populations of cutthroat trout in a small Colorado lake. Trans. Am. Fish. Soc. 103(3):423-430.
- Utter, F. M. and G. Ridgway.
1966. Serological evidence for inbreeding of Lahontan cutthroat trout, Salmo clarki henshawi, in Summit Lake, Nevada. Calif. Fish and Game 52(3):180-184.
- Wheeler, S. S.
1969. The desert lake. Caxton Printers, Caldwell, Idaho. 133 p.



PAIUTE TROUT
Salmo clarki seleniris

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral line)	150-180
and above lateral line	
(origin of dorsal fin to lateral line)	33-40
Vertebrae	60-63
	(mean 61.8)
Gillrakers	21-27
	(mean 24)
Pyloric caecae	50-70
Basibranchial teeth	2-15
(Behnke 1960, personal data from specimens taken from Silver King Creek, California, 1933-1956)	

SPECIES DESCRIPTION

The Paiute (sometimes spelled Piute) trout was described by Snyder (1933) from above a barrier falls in the headwaters of Silver King Creek, Alpine County, California.

Silver King Creek is tributary to the East Fork of the Carson River of the Lahontan basin. Snyder recognized the affinities and derivation of the Paiute trout from S. c. henshawi, the trout native to the Lahontan basin. The absence of spots on the body seemed like such a striking diagnostic

character to Snyder that he described "Salmo seleniris" as a new species and became somewhat poetical in his selection of a specific name which suggested "...a fanciful resemblance of its evanescent tints to the lunar rainbow" (Snyder 1934).

Snyder's publication, however, provided little data on the taxonomic characters of the Paiute trout, particularly concerning its range of variability and an adequate comparison with S. c. henshawi. No published taxonomic data has appeared since to supplement his original work, but a Master of Arts thesis by Behnke (1960) and subsequent data which he has accumulated reveals that S. c. seleniris has nearly identical values to S. c. henshawi in all of its meristic characters. Data on S. c. seleniris which appear above are published here for the first time.

The gillraker number indicates that the separation of S. c. seleniris in Silver King Creek from an ancestral S. c. henshawi occurred after S. c. henshawi had attained its ultimate number of gillrakers in pluvial Lake Lahontan under lacustrine selective pressures, no more than about 5,000 to 8,000 years ago. The Paiute trout, then, probably was not derived from the primordial trout which invaded the Lahontan basin, but developed instead rather recently, differing from S. c. henshawi only in spotting pattern. Most likely the phylogenetic separation of S. c. seleniris from S. c. henshawi in the Carson River drainage occurred after the isolation of the various stocks of S. c. henshawi in the Truckee,

Carson and Walker river systems by the desiccation of Lake Lahontan.

Even the absence of spots on the body as a character to differentiate S. c. seleniris from S. c. henshawi cannot be used as absolutely as originally believed. Stephen Nicola, California Department of Fish and Game, carefully examined 79 of the specimens of S. c. seleniris taken from Silver King Creek in 1933 and found that while 47 specimens had no spots, 32 had from one to nine spots on the body (S. Nicola, personal communication to R. Behnke, 5 June 1974).

DISTRIBUTION

When Snyder described the Paiute trout in 1933, he assumed that it had originated in Silver King Creek above Llewellyn Falls and was limited to the known distribution at that time. But Silver King Creek above Llewellyn Falls was originally barren of fish; it had been stocked by a sheepherder with trout taken from lower Silver King Creek in 1912. Another transplant above the falls took place in 1924. The subsequent discovery in 1946 of Paiute trout in Corral Valley and Coyote Valley, two isolated tributaries to lower Silver King Creek, was attributed to an early but unknown introduction by man, which may have occurred as early as the 1860's when Canadian loggers worked in the area (Baugh 1973). Stephen Nicola kindly provided to Robert Behnke the information on these transplants, which is filed in the office of the California Department of Fish and Game, Sacramento, and taken from statements made in 1944 by Mr. Virgil Connell, a stockman who pastured sheep in the Silver King watershed.

Mr. Connell's statements raise a question on the original distribution of Paiute trout. If the stream above Llewellyn Falls was devoid of trout prior to 1912, and if the introduced trout came from lower Silver King Creek, then the original range must have included the Silver King drainage above some natural barrier which prevented interbreeding with the typical Lahontan cutthroats of the East Carson River system.

By the time Snyder described S. c. seleniris in 1933, the trout below Llewellyn Falls had thoroughly hybridized with rainbow trout (Behnke 1960). It would be interesting to know the date of the first introduction of rainbow trout, and of Lahontan cutthroat trout, into the Silver King drainage.

The present known distribution of Paiute trout consists entirely of introduced populations which include those in Fly Valley and

Four Mile Canyon Creeks (isolated tributaries to Silver King Creek); North Fork Cottonwood Creek and Cabin Creek, Mono County; Birchim Lake, Inyo County; and Delany Creek, Yosemite National Park, where the National Park Service is attempting to remove brook trout to sustain the Paiute population.

STATUS AND POPULATION TRENDS

Silver King Creek was closed to fishing above Llewellyn Falls in 1933, after S. c. seleniris was discovered there. But when angling restrictions were removed in 1952 it was found that Paiute trout, like most cutthroat trout living in streams, was easily caught and vulnerable to over-exploitation. But it was the apparently inadvertent stocking of 5000 rainbow trout above Llewellyn Falls by the California Department of Fish and Game in 1949 which dealt the final blow to the Paiute trout as a pure form in Silver King Creek. A common fishery management practice at that time was to "seed" headwater mountain streams with "new blood" in the form of hatchery trout fry, even though evidence had long accumulated to demonstrate the worthlessness of such stocking. After the 1949 rainbow trout stocking, Lahontan cutthroats were mistakenly dropped by airplane into Whitecliff Lake, which flows into Bull Creek and joins Silver King Creek just above Llewellyn Falls.

In 1957, investigators found hybrid fish with spots above Llewellyn Falls and by 1963 they considered the Silver King Creek population a hybrid swarm. Paiute trout populations in Corral and Coyote Valleys had by 1963 also thoroughly hybridized with rainbow trout from an unknown introduction; half the specimens lacked basibranchial teeth, and gillraker numbers ranged from 19-24, versus 21-27 in pure Paiute trout. These specimens also exhibited a profusion of spots on the body (R. Behnke, personal notes and data).

Fortunately, pure Paiute trout had been introduced and established into formerly barren Fly Valley, Four Mile Canyon and North Fork Cottonwood Creeks to ensure its perpetuation.

Treatment with rotenone in 1964 of Silver King Creek above Llewellyn Falls attempted to eliminate hybrids, and pure Paiute trout were re-introduced (McAfee 1966, Staley 1965). But some hybrids survived the poisoning because of extensive beaver pond areas which made thorough treatment difficult and by 1968 fish with spots on the body again occurred.

The Threatened Trout Committee of the California Department of Fish and Game, in light of the failure of chemical treatment in

Silver King Creek, has instituted an alternative management practice of annual electrofishing in the creek above Llewellyn Falls with selective removal of fish which display more than five spots on the body. The efficacy of this technique is currently being tested (Ryan and Nicola, 1976).

The U. S. Department of the Interior had officially listed S. c. seleniris as an endangered species, but because of management problems resulting from the "endangered" classification (see chapter on S. c. stomias, page 19), the California Department of Fish and Game petitioned the Interior Department to change the status to "threatened." The official change in status from "endangered" to "threatened" took place in July, 1975 (Federal Register 140 (37), 16 July 1975).

All present pure populations of self-reproducing Paiute trout occur in small, isolated environments, but the nucleus exists to intensify restoration projects.

LIFE HISTORY

Some life history information appears in McAfee (1966). Darrel Wong (1975) and James Diana (1975) present more detailed data based on studies of the North Cottonwood Creek population.

Paiute trout attain a length of only 23 to 25 cm in small streams such as the headwaters of Silver King Creek, but are known to reach lengths of up to 46 cm in larger bodies of water such as Birchim Lake (McAfee 1966).

The most significant life history attribute of the Paiute trout in relation to management must be implied from a knowledge of its evolutionary history. S. c. seleniris has been completely isolated from other species of fish for probably several thousand years, ever since its separation, in Silver King Creek, from a Lahontan cutthroat trout ancestor. The cutthroat in other areas of the Lahontan basin evolved with a diverse fauna of several species of minnows and suckers, a whitefish, and a sculpin. Selective pressures can differ greatly between populations coexisting with a diversity of species and those developing in isolation, with the result that life history and behavioral characteristics of isolated fishes may prevent them from coexisting successfully with other species. It must be assumed that a transplant of Paiute trout will stand a

good chance of success only in waters barren of other fishes.

HABITAT REQUIREMENTS AND LIMITING FACTORS

Although the ancestral trout of the Lahontan basin lived as a large, lacustrine predator in pluvial Lake Lahontan, the Paiute trout has evolved in a small, cold stream environment. Since it thrives also in Birchim Lake, it can be expected that the Paiute trout can adapt successfully to virtually any suitable trout waters. The ultimate limiting factor, though, may be the presence of other fishes, particularly trouts.

Schneegas and Pister (1967) and Ashley (1970) have written habitat management plans for the Paiute trout.

PROTECTIVE MEASURES

To insure protection of the upper Silver King Creek watershed, the Toiyabe National Forest and the Sierra Pacific Power Company transacted a land exchange in 1971 which made most of the watershed public land. The U. S. Marine Corps agreed to discontinue its use of the watershed for survival training in 1963. After the poisoning of Silver King Creek to remove hybrids in 1964, pure Paiute trout were reintroduced. But hybrids reappeared and the California Department of Fish and Game is attempting to control them by annual electrofishing. The construction of a barrier on Four Mile Canyon Creek in 1972 will hopefully insure the isolation of Paiute trout there.

Transplant programs have established several new populations (see page 29).

The Threatened Trout Committee of the California Department of Fish and Game provides the structure to coordinate state and federal efforts to protect and enhance the distribution and abundance of this trout.

RECOMMENDATIONS

Pure populations of S. c. seleniris no longer exist in its native waters. The extremely limited natural distribution and catastrophic decline in abundance of such a fish may make it a matter of common sense not to restrict restoration efforts to the native range. Although California's Threatened Trout Committee has not yet formalized its thinking in this matter, the current view is that Silver King Creek and its tributaries down to a point below the confluence of

Corral Valley Creek and North Fork Cottonwood Creek will be the extent of its restoration efforts, although protection of Paiute trout in Cabin Creek and Birchim Lake will remain in force also (S. Nicola, personal communication to R. Behnke).

The Paiute trout could become an integral part of trout management in mountain lakes if a brood stock lake, similar to Heenan Lake for S. c. henshawi propagation, were established, since many mountain lakes lack adequate spawning area for trout of the genus Salmo to maintain self-reproducing populations, and must be stocked with trout fry dropped from aircraft. The potential of S. c. seleniris, as a rare and beautiful trout, to lure hikers to more remote and little-used areas of national forests could serve as a possible "crowd dispersal" technique in fishery and wilderness management.

Streams with natural barriers and small lakes having potential spawning tributaries but now harboring non-native trouts should be considered for chemical treatment to eliminate present trout populations and to establish additional self-perpetuating populations of S. c. seleniris.

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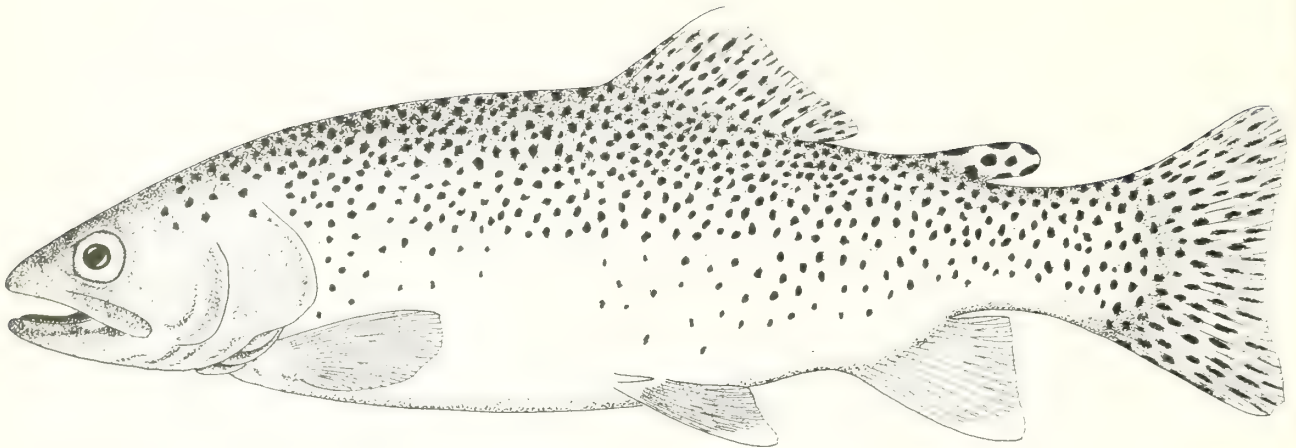
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North Cottonwood Creek and Birchim Lake)

REFERENCES

- Ashley, R. R.
1970. Habitat management plan, Piute trout.
USDA Forest Service, Toiyabe Nat. For. 15 p.
- Baugh, T.
1973. To save a species. Nevada Outdoors
7(3):24-26.
- Behnke, R. J.
1960. Taxonomy of the cutthroat trout of
the Great Basin with notes on the rainbow
series. M. A. Thesis, Univ. California,
Berkeley. 98 p.
- Dunham, D. K.
1968. Preliminary survey analysis of Silver
King Creek habitat above Llewellyn Falls,
Alipine County, California. U.S. For. Serv.
Toiyabe Nat. For. 10 p.
- McAfee, W. R.
1966. Paiute cutthroat trout. In A. J.
Calhoun (ed.), Inland Fisheries Management.
Calif. Dept. Fish and Game, Sacramento.
p. 231-233.
- Ryan, J. H., and S. J. Nicola.
1976. Status of the Paiute cutthroat trout,
Salmo clarki seleniris Snyder, in Califor-
nia. Draft Rep. of Threatened Trout Comm.,
Calif. Dept. Fish and Game. 59 p.
- Schneegas, E. R. and E. P. Pister.
1967. Piute trout habitat management plan.
USDA Forest Service, Inyo Nat. For. 30 p.
- Snyder, J. O.
1933. Description of Salmo seleniris, a
new California trout. Proc. Calif. Acad.
Sci. 20(11):471-472.

_____.
1934. A new California trout. California
Fish and Game 20(2):105-112.
- Vestal, E. H.
1947. A new transplant of the Piute trout
(Salmo clarki seleniris) from Silver King
Creek, Alpine County, California. Calif-
ornia Fish and Game 33(2):89-96.



GILA TROUT
Salmo gilae

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral line)	135-165
and above lateral line	
(origin of dorsal fin to lateral line)	29-38
Vertebrae	59-63 ^{a/}
Pyloric caecae	25-46
	(means 33-36) ^{b/}
	43-57
	(mean 47.2) ^{c/}
Basibranchial teeth	Absent ^{d/}

[Taxonomic data from Behnke (1973) and personal data; and from David (1976).]

^{a/}Mean values for samples from four localities range from 59.7 for Spruce Creek specimens to 61.7 for McKenna Creek specimens.

^{b/}Values from specimens from Main Diamond, South Diamond and McKenna Creeks

^{c/}Values from specimens from Spruce Creek

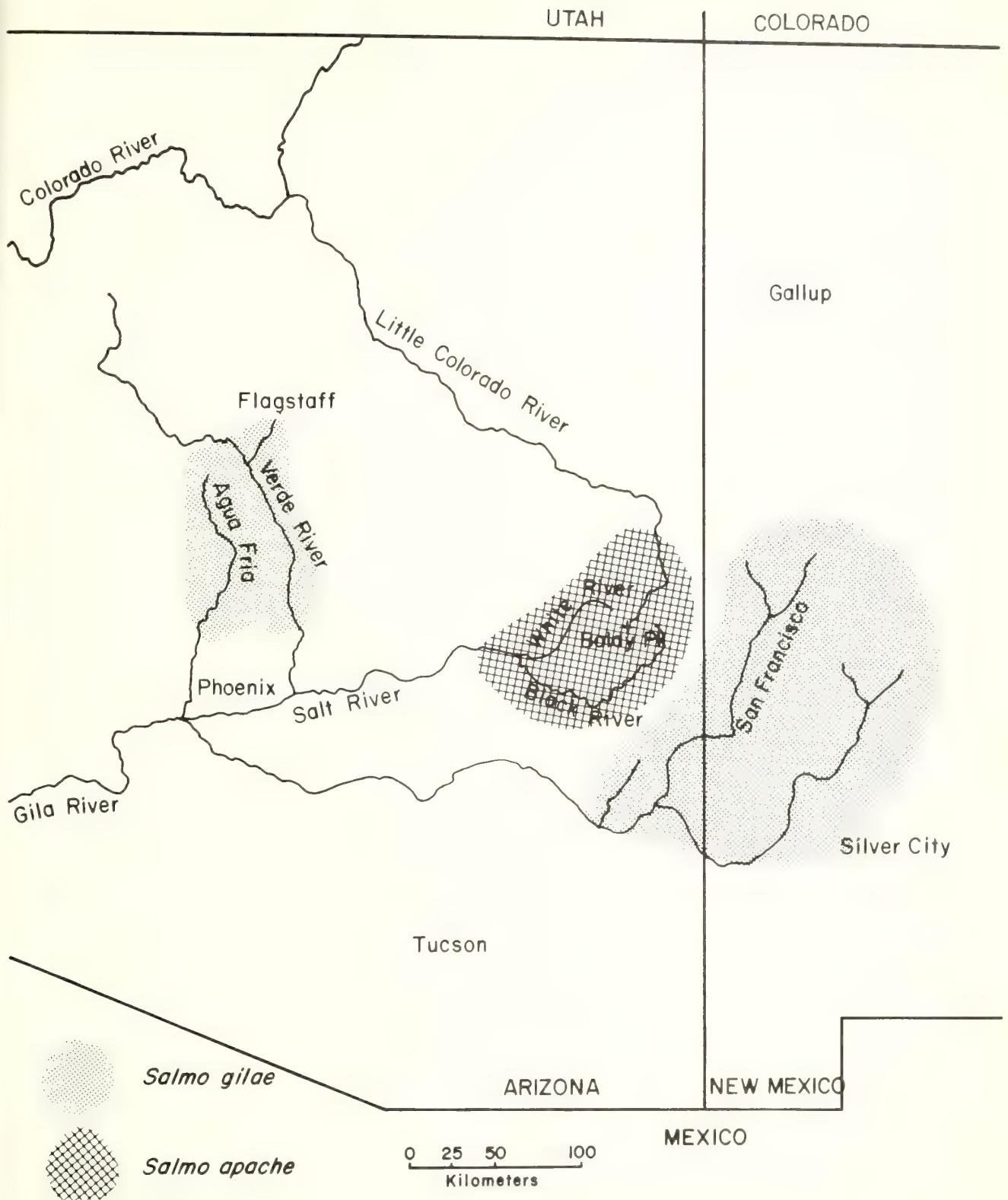
^{d/}Absent in all New Mexico specimens examined except those in Spruce Creek. Basibranchial teeth were also present in three of four specimens collected from Verde River drainage of Arizona in 1888-89.

SPECIES DESCRIPTION

Although a native trout was historically known from the Gila River basin of New Mexico, it was not until this trout was on the brink of extinction that it was recognized as distinct and described as a new species by R. R. Miller (1950).

A problem with providing an adequate diagnosis of Salmo gilae is that the original description is based on a population in tiny, intermittent Main Diamond Creek and certainly does not encompass the range of natural variability of this trout throughout its original range. Miller (1972) considered the original range of the Gila trout to include the Verde River system of Arizona (where the native trout is now extinct). Four specimens collected from Oak Creek, south of Flagstaff, in 1888 and 1889, and now in the U. S. National Museum, have the spotting pattern typical of the species (Miller 1972, fig. 5), but three of the four possess basibranchial teeth, a character not previously reported in S. gilae in the Gila River basin of New Mexico. However, David (1976) found basibranchial teeth in four of 12 specimens of Gila trout from Spruce Creek, a tributary of the San Francisco River system of New Mexico.

A distinctive feature of S. gilae is the profuse pattern of small, irregularly-shaped spots, mainly above the lateral line on the



Map 4. Indigenous distribution of Salmo gilae and Salmo apache.

body, onto the head, and on the dorsal and caudal fins. The basic coloration is yellowish or olive-yellow on the sides of the body; a faint rose band may be present along the lateral line in adults. A yellow cutthroat mark is present and the dorsal, anal and pelvic fins are tipped with white or yellow.

Salmo gilae is reputed to have a unique karyotype (number and morphology of chromosomes) which differentiates it from all other trouts (R. R. Miller, personal communication to R. Behnke). Mr. Robert David, New Mexico State University, has studied the chromosomes of S. gilae after completion of his thesis. Preliminary analysis indicates a karyotype different from any other trout (personal communication to R. Behnke).

Gila trout which have hybridized with rainbow trout are common in many tributaries of the upper Gila River. They exhibit erratic spotting and coloration, higher vertebral and caecal counts and lower scale counts.

DISTRIBUTION

Little information exists to accurately define the original distribution of the Gila trout. Miller (1950) documented its occurrence throughout the upper Gila River watershed downstream to the town of Cliff, New Mexico, in 1896, but it reputedly was absent from the San Francisco drainage of New Mexico and Arizona. Miller (1972) evaluated museum specimens collected from the Verde drainage, Arizona, a tributary to the Salt River of the Gila River basin, and pronounced them to be Salmo gilae. The present population of Gila trout in Spruce Creek, New Mexico, a headwater tributary in the San Francisco drainage, is attributed to an introduction in 1905 (Miller 1950).

The zoogeography of the distribution of S. gilae is puzzling. One would expect that S. apache, the native trout in the headwaters of the Salt River system, should also be the trout native to the Verde drainage of Arizona. And if S. gilae once had direct communication from the upper Gila basin of New Mexico with the Verde drainage of Arizona, why were no remnant populations discovered in the San Francisco River system? This distributional enigma is further compounded by the fact that the only known museum specimens of native trout from the San Francisco River system (K. P. Creek, Arizona) have the typical spotting pattern of S. apache (Miller 1972, fig. 4).

In 1975, trout specimens from Sycamore Creek, Arizona, a tributary to the Agua Fria

River (the next drainage west of the Verde system), were collected by Mr. Gary Edwards of the Arizona Department of Game and Fish and sent to Robert Behnke for identification.

Although the Sycamore Creek population has hybridized with rainbow trout, enough of the original genotype remains to indicate that the native trout of Sycamore Creek had a spotting pattern typical of S. gilae.

Thus, S. gilae was probably native to both the Verde and Agua Fria drainages of Arizona. Needham and Gard (1959) described a trout from the Rio Yaqui of Mexico, a contiguous basin with the Gila River, which appears similar to S. gilae.

Unfortunately, the almost complete elimination of both S. gilae and S. apache from their native ranges before either of these species was studied, prevents a better understanding of their original distribution.

Presently, pure or essentially pure populations are known from Main Diamond, South Diamond and McKenna Creeks, New Mexico. The Spruce Creek population in the San Francisco drainage is attributed to an early introduction, but the lower number of vertebrae, higher number of pyloric caecae and the report of basibranchial teeth in specimens from this population indicate that Spruce Creek trout are well-differentiated from other S. gilae in New Mexico. This might be construed as evidence supporting the indigenous occurrence of S. gilae in the San Francisco drainage. Further support of such native distribution is given by the former occurrence of S. gilae in Eagle Creek, the next major tributary to the Gila River west of the San Francisco River (Mulch and Gamble 1956). David (1976) discovered a population of pure S. gilae in Iron Creek, an isolated tributary to the Middle Fork of the Gila River.

A cooperative project between the U. S. Forest Service, New Mexico Department of Game and Fish, and New Mexico State University introduced Gila trout from Main Diamond Creek into McKnight Creek of the Mimbres River basin in 1970 and 1972, after construction of a barrier and elimination of a sucker population. These trout have successfully reproduced (R. David and Douglas Jester, New Mexico State University, personal communication to R. Behnke).

Another project transplanted 89 Gila trout from Main Diamond Creek into barren Sheep Corral Creek, a tributary to Sapillo Creek in the Gila drainage, New Mexico.

Although stream improvement devices were placed into Sheep Corral Creek, the problem of livestock overgrazing remains and the degraded habitat has had no chance to recover. A 1975 survey of Sheep Corral Creek found 15 trout from the 1972 transplant, but no sign existed that successful reproduction had occurred. Probably S. gilae cannot become established in Sheep Corral Creek until the grazing problem is corrected (R. David, personal communication to R. Behnke).

The Arizona Game and Fish Department transplanted S. gilae from Main Diamond Creek, New Mexico into Gap Creek, a barren tributary of the Verde drainage in 1974, in an attempt to restore this species to the Verde system. A more ambitious program to restore the Gila trout to its historic range in Arizona was delayed by the loss of a hatchery brood stock in 1974 (Gary Edwards, Arizona Game and Fish Department, personal communication to R. Behnke).

STATUS AND POPULATION TREND

Miller (1950, 1961) described the former abundance and rapid decline to almost extinction of S. gilae. Hybridization throughout the upper Gila basin resulting from the introduction of rainbow trout was so extensive that by 1950 the very few pure populations of Gila trout which remained were all isolated by barriers in small headwater streams. Subsequent re-introduction programs in New Mexico and Arizona have met with modest success and the distribution and abundance of this rare trout have increased in recent years.

Salmo gilae is officially recognized as an endangered species under the Endangered Species Act of 1973.

LIFE HISTORY

Two Master of Science theses have been prepared on the Gila Trout of Main Diamond Creek (Regan 1964, Hanson 1971). Although these studies present detailed information on age, growth, food habits and fecundity of the trout and on physical, chemical and biological parameters of the water, this information reveals but certain life history characteristics as determined by the harsh environment of Main Diamond Creek. These studies are of limited value in predicting adaptability to new waters except to indicate that a trout which can thrive in Main Diamond Creek is

likely to do well in almost any trout habitat, as long as no other fish are present. The growth potential of S. gilae almost certainly is greater than the 23 cm maximum size it attains in Main Diamond Creek.

Most probably, the original S. gilae found in the upper Gila basin did not consist of a single homogeneous population, but instead was composed of several discrete stocks in the smaller tributaries and probably another stock utilizing the main river and larger tributaries; these separate stocks probably possessed slightly differing life history characteristics. The assumption of discrete populations and genetic heterogeneity is supported by the taxonomic differences found between existing populations, particularly when Spruce Creek specimens are compared with other samples of S. gilae.

HABITAT REQUIREMENTS AND LIMITING FACTORS

Present S. gilae populations appear sufficiently adaptable to live in any waters suitable for any species of trout, even though originally this species probably consisted of disjunct populations with differing ecological specializations. A major limiting factor, though, remains the presence, in potential Gila trout habitat, of other species of trout; rainbow trout hybridize with S. gilae and brook and brown trout compete with it for food and space. Any stream presently holding brook, brown, or rainbow trout can provide suitable habitat for S. gilae after all exotic trouts are eliminated and prevented from re-invasion.

PROTECTIVE MEASURES

Main Diamond, South Diamond, McKenna, Iron and Spruce Creeks are in the Gila Wilderness Area of the Gila National Forest; thus they are endowed with some extra legal protection from habitat degradation.

The "endangered" status granted the Gila trout under the Endangered Species Act of 1973 prohibits its "taking" or "harassment," but prohibiting angling for an endangered trout, particularly in remote areas, may not be relevant to the protection of the species except in a negative way, since any large-scale restoration effort must be based on introduction into public waters. Subsequent closure of such waters to angling can create unfavorable response to such projects and inhibit realization of the desired goal. However, due to the extreme rarity of S. gilae, it may not be wise to remove the species from

the endangered list until the Little Creek restoration project has been successfully completed.

McKnight Creek has suffered habitat degradation from livestock overgrazing. The U. S. Forest Service initiated corrective measures in 1975 and also plans to institute grazing control in the Sheep Corral watershed in 1976 (Douglas Jester, personal communication to R. Behnke).

The Gila trout recovery team has drafted an outline of a Gila trout recovery plan (January 19, 1976). Included in the plan is a re-introduction of S. gilae into Little Creek after construction of a barrier and elimination of hybrids.

The Arizona Department of Game and Fish plans to re-establish a brood stock of Gila trout for introductions into the Verde and, perhaps, Agua Fria drainages (G. Edwards, personal communication to R. Behnke).

Section 7 of the Endangered Species Act of 1973 directs all federal agencies to carry out programs for conservation of endangered and threatened species and to prevent any of their activities from jeopardizing the continued existence of these species.

RECOMMENDATIONS

If the Little Creek restoration project meets with success, the Gila trout should be changed in status from "endangered" to "threatened." This change will facilitate management of the species and stimulate further transplants into public waters.

The population in South Diamond Creek exhibits the most uniform appearance of all known existing populations of S. gilae; as the most ideal representative of the species, at least some future transplants should be made from this population.

Robert David's research has revealed some populations of trout which, although slightly hybridized, exhibit a predominant S. gilae phenotype. Such populations should be protected against future introductions of non-native trout.

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REFERENCES

Behnke, R. J.

1970. New information on Gila trout, Salmo gilae. Rare and endangered species report. Colorado Cooperative Fishery Unit, Colorado State University, Ft. Collins, 12 p. (mimeo)

1973. Gila trout, Salmo gilae. Endangered species report, prepared for U.S. Fish and Wildlife Service, Region II, Albuquerque, N.M. 5 p. (mimeo)

David, R. E.

1976. Taxonomic analysis of Gila and Gila x rainbow trout in southwestern New Mexico. M.S. thesis, New Mexico State University, Las Cruces, N.M. 36 p.

Hanson, J. N.

1971. Investigations on Gila trout, Salmo gilae Miller, in southwestern New Mexico. M. S. Thesis, New Mexico State University, Las Cruces. 44 p.

Miller, R. R.

1950. Notes on the cutthroat and rainbow trout with the description of a new species from the Gila River, New Mexico. Occ. Pap. Mus. Zool. Univ. Mich. 529. 42 p.

1961. Man and the changing fish fauna of the American Southwest. Pap. Mich. Acad. Sci., Arts, Letters 46:365-404.

1972. Classification of the native trouts of Arizona with the description of a new species, Salmo apache. Copeia 3:401-422.

Mulch, E. D. and W. C. Gamble.

1956. Game fishes of Arizona. Arizona Game and Fish Department, Phoenix. 19 p.

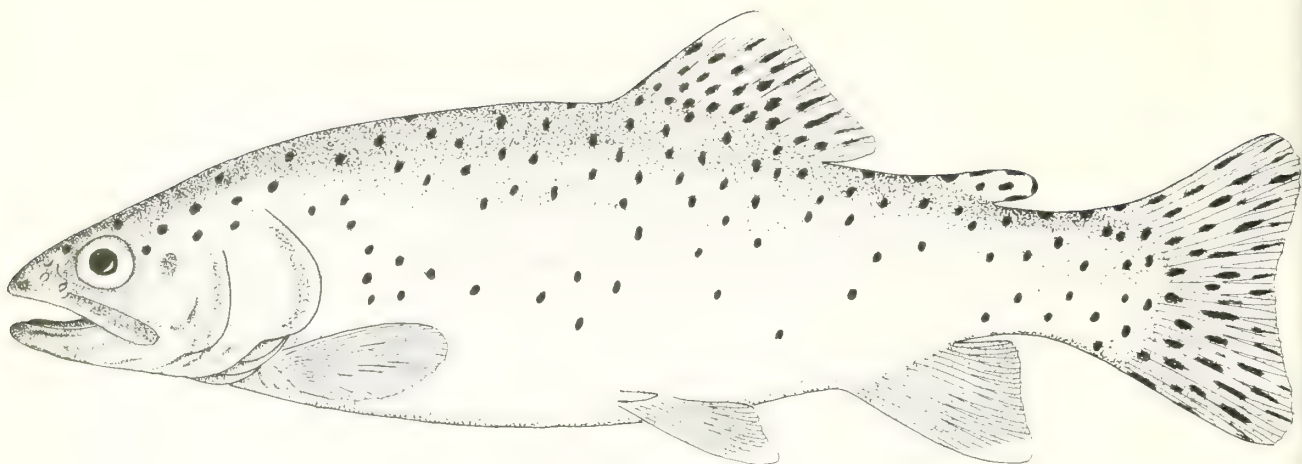
Needham, P. R. and R. Gard.

1959. Rainbow trout in California and Mexico with notes on the cutthroat series. Univ. of Calif. Publ. Zool. 67(1): 124 p.

Regan, D.

1964. Ecology of the Gila trout (Salmo gilae) in Main Diamond Creek, New Mexico. M. S. Thesis, Colorado State Univ., Ft. Collins. 57 p.

1966. Ecology of Gila trout in Main Diamond Creek, New Mexico. U. S. Fish and Wildlife Service, Tech. Pap. Sport Fish. 5. 24 p.



ARIZONA NATIVE TROUT
Salmo apache

TYPICAL MERISTIC CHARACTERS

Scale counts	
lateral series	
(two rows above lateral lines)	133-172 (mean 146-158)
and above lateral line	
(origin of dorsal fin to lateral line)	32-40 (mean 34-36)
Vertebrae	58-61 (mean 59.5-60)
Pyloric caecae	21-41 (mean 26.7-32.9)
Basibranchial teeth	Vestigial

SPECIES DESCRIPTION

Pyloric caecae counts are among the lowest of American trouts; basibranchial teeth are vestigial, with only five to 10 percent of the specimens of some populations possessing these teeth (Behnke 1970, 1973, personal data).

The basic coloration of Salmo apache resembles that of S. gilae, with olive-yellow to golden-yellow on the sides and ventral region, a yellow cutthroat mark and whitish tips on the dorsal, pelvic and anal fins. While S. apache lacks the rose-red lateral band typical of S. gilae, the spotting pattern constitutes the most pronounced phenotypic difference between the two trouts. S. apache

displays larger roundish or oblong spots, similar to interior cutthroat trouts, over the sides of the body, onto the top of the head and on the dorsal, caudal and adipose fins (Miller 1972, fig. 2). S. apache typically possesses the largest dorsal fin of any American trout.

The unique karyotype of S. apache shows 56 chromosomes with 106 arms, and may be derived from a cutthroat trout-like ancestor (Miller 1972).

DISTRIBUTION

Cope and Yarrow (1875) first recorded trout in the White River, Arizona (in the headwaters of the Salt River system of the Gila River Basin) in 1873, and referred to them as a variety of the Colorado River cutthroat trout. Jordan and Evermann (1896) referred to the trout in the headwaters of the Little Colorado River in Arizona also as the Colorado River cutthroat. When Miller (1950) described S. gilae, he also mentioned native trout in the headwaters of the East Fork of the White River in Arizona and provisionally included them with the Gila trout as S. gilae. After further study and examination of many more specimens Miller became convinced of the uniqueness of this trout and described it as a new species, Salmo apache (Miller 1972).

By this time, the range of S. apache had been so diminished that the original

distribution was impossible to determine with certainty. Miller (1972) considered its native range to include the upper Salt River system of Arizona (Black and White River drainages) and the headwaters of the Little Colorado River. A museum specimen taken in 1904 from K. P. Creek, a tributary of the Blue River of the San Francisco drainage of Arizona, shows spotting patterns characteristic of S. apache and not S. gilae (Miller 1972, fig. 4). Perhaps both species were native to the San Francisco drainage of Arizona, but in this case it would be expected that hybridization between them would have produced an array of intergrading populations.

The present known natural distribution of S. apache includes: Ord Creek, Firebox Creek, Deep Creek, and headwaters of the East Fork of the White River; the upper Bonito Creek watershed, a tributary to the Black River. All of these streams are on the Fort Apache Indian Reservation. The only known population of S. apache in the Little Colorado River basin exists in Paddy Creek, between the towns of Alpine and Nutrioso, Arizona, near the New Mexico border. A survey conducted in 1967 by John Anderson, U.S. Fish and Wildlife Service biologist, and Robert Behnke determined that recently introduced brook trout had become abundant in Paddy Creek. Thus, the outlook for the perpetuation of the only known population of S. apache in the Little Colorado River basin appears doubtful.

S. apache has been propagated at the Sterling Springs Hatchery, Arizona, and a population has been established in Christmas Tree Lake, a sport fishing lake created specifically for this species' restoration on the Fort Apache Indian Reservation. The Sterling Springs Hatchery is under renovation and a new brood stock is currently being established (Joe Stone, personal communication to Robert Behnke). The propagation and reintroduction program for S. apache conducted by the Arizona Department of Game and Fish has resulted in the establishment of new stream populations in Grant, Home, Mineral, and North Canyon Creeks and streams on Graham Mountain (Robert Jantzen, Director, Arizona Department of Game and Fish, letter to Lynn Greenwalt, Director, U. S. Fish and Wildlife Service; Joe Stone, personal communication to Robert Behnke).

STATUS AND POPULATION TREND

Even though S. apache possesses many distinctive characters including a unique chromosome complement, no genetic barriers exist against hybridization with rainbow or cutthroat trout. The introduction of rainbow trout into waters of the White Mountains of Arizona began hybridization which spread throughout the watersheds until only remnant pure populations of S. apache persisted in a relatively few headwater areas. Due to this precarious situation, the U. S. Department of the Interior listed the Arizona trout as endangered. But the endangered status interfered with management and restoration efforts and prohibited angling (Christmas Tree Lake on the Fort Apache Indian Reservation was constructed and stocked with S. apache for use as a native trout fishery), so the status of S. apache was officially changed from "endangered" to "threatened" (Federal Register 40 (137), 16 July 1975).

While S. apache has been virtually eliminated from its native range, it has survived in greater numbers than S. gilae. In some streams, such as upper Ord Creek, S. apache had been found to coexist in good abundance with both brown trout and brook trout. But 1974 electrofishing in Ord Creek showed brook trout to be dominant and Arizona trout, rare (Ron Guntow, personal communication to Robert Behnke, 2 October 1975).

LIFE HISTORY

As Miller (1972) pointed out, almost nothing is known of the life history of S. apache except for the significant fact that its reproductive season and spawning behavior must be sufficiently similar to rainbow trout to permit hybridization. Not all S. apache populations are completely isolated from introduced trouts. But while brook trout, brown trout, rainbow trout, and rainbow X S. apache hybrids have replaced pure S. apache in larger streams at lower elevations and in disturbed habitat, S. apache has been able to survive with brook trout and brown trout in Ord Creek and has persisted in the headwaters of the East Fork of the White River and in the upper Bonito Creek watershed without protection by absolute physical barriers or from introductions of non-native trouts. Such situations resemble examples of native cutthroat trout maintaining their integrity in undisturbed headwater areas where they possess the most fit genotypes for colder waters and associated environmental conditions. Disruption and degradation of pristine headwater environments typically lead to hybridization with rainbow trout and/or replacement by brown trout or brook trout.

The growth potential of S. apache remains unknown, but the largest specimen known from Christmas Tree Lake, a spent female, measured 48.8 cm and weighed 0.9 kg (Ron Gumtow, personal communication to Robert Behnke).

HABITAT REQUIREMENTS AND LIMITING FACTORS

The introduction of non-native trouts may not pose as severe a threat to S. apache as it does to S. gilae in cold headwater streams as long as the integrity of the habitat is not violated. The complete replacement of S. apache at lower elevations and in disturbed areas demonstrates that this species is placed at a competitive disadvantage in such situations. The entire upper Bonito Creek watershed, which contains the most abundant populations of S. apache, is currently being logged. While guidelines for habitat protection have been provided to the logging operation, they have no legal standing and some damage to the stream has already occurred (Richard Baldes and Ron Gumtow, personal communication to Robert Behnke). The impact of logging on the Bonito Creek watershed and on S. apache is under study, but data sufficient for basing forecasts are not yet available.

PROTECTIVE MEASURES

The Apache Indian Tribe has closed the waters of Ord Creek to fishing in order to protect the Arizona trout.

The Office of Endangered Species, U. S. Department of the Interior, lists S. apache as a threatened species (Federal Register 40 (137), 16 July 1975).

The Arizona Department of Game and Fish has propagated S. apache at their Sterling Springs hatchery from brood stock developed from Ord Creek trout. At least four new stream populations have been established. The brood stock was lost in 1974 but the hatchery is undergoing renovation and a new brood stock is being established (Gary Edwards, Joe Stone, personal communications to Robert Behnke).

Bruce Rosenlund (U. S. Fish and Wildlife Service, Alchesay-Williams National Fish Hatchery, Whiteriver, Arizona) has been conducting disease and parasite studies on S. apache to determine the presence of fish pathogens which could be serving as limiting factors to endangered populations in the wild, and to determine the feasibility of transferring endangered fish to a hatchery for propagation.

Ken Harper (Arizona Cooperative Fishery Unit, USDI, 210 Biological Sciences East, University of Arizona, Tucson, Arizona, 85721) is conducting graduate research to determine the effects of logging on S. apache in the Bonito Creek watershed. This project, initiated in 1974, is due for completion in 1976.

RECOMMENDATIONS

The Apache Indian tribe has, in the past, demonstrated a sincere interest in perpetuating the Arizona trout, but the recreational resources of the reservation are nonetheless a business enterprise and heretofore the tourist fishery has been based mainly on stocking great numbers of rainbow trout, particularly in a series of recreational lakes created on the reservation.

Ronald Gumtow, biologist with the U. S. Fish and Wildlife Service and advisor on fisheries management to the tribe, stresses a greatly expanded emphasis on the use of S. apache in sport fisheries management on reservation waters in the future. The former endangered status of S. apache prohibited angling and voided any economic gains to the tribe from the potential fishing in Christmas Tree Lake. Now that the status of S. apache has been changed from endangered to threatened, the lake can be opened to fishermen (for a fee) and similar fisheries for S. apache can be established.

The emphasis on native trout fisheries versus hatchery trout fisheries is one of quality versus quantity; the greater value lies with trout in the water rather than trout in the creel. The economic rationale is that with proper publicity and public interest, the tourist fisherman will be willing to pay more for the opportunity to fish for a rare and beautiful native trout than to fish for the common hatchery rainbow trout.

Before S. apache can be widely used to create new fisheries in reservation lakes, data must be gathered from Christmas Tree Lake on age, growth, vulnerability to exploitation and population structure under exploitation to provide information on optimum stocking rates and to design special regulations on size and bag limits to maintain maximum recreational values.

The watersheds of streams on the Apache Reservation and elsewhere with populations of S. apache should be granted special protection from possible future despoilation, comparable to wilderness areas of national forests.

Off the reservation, the reintroduction of S. apache into barren streams and recreational lakes should be stepped up. This recommendation is, in part, dependent on the success of hatchery propagation.

Paddy Creek, the only known locality in the Little Colorado River basin with a native population of S. apache, should be monitored to determine the impact of brook trout on S. apache. The 1967 survey of Paddy Creek by Anderson and Behnke noted that the headwaters above a barrier falls were barren of all fish. If S. apache still exists in Paddy Creek, a transplant above the barrier should be made as soon as possible.

Specimens from previously unsampled localities should be evaluated for relative purity in an attempt to discover new populations of S. apache.

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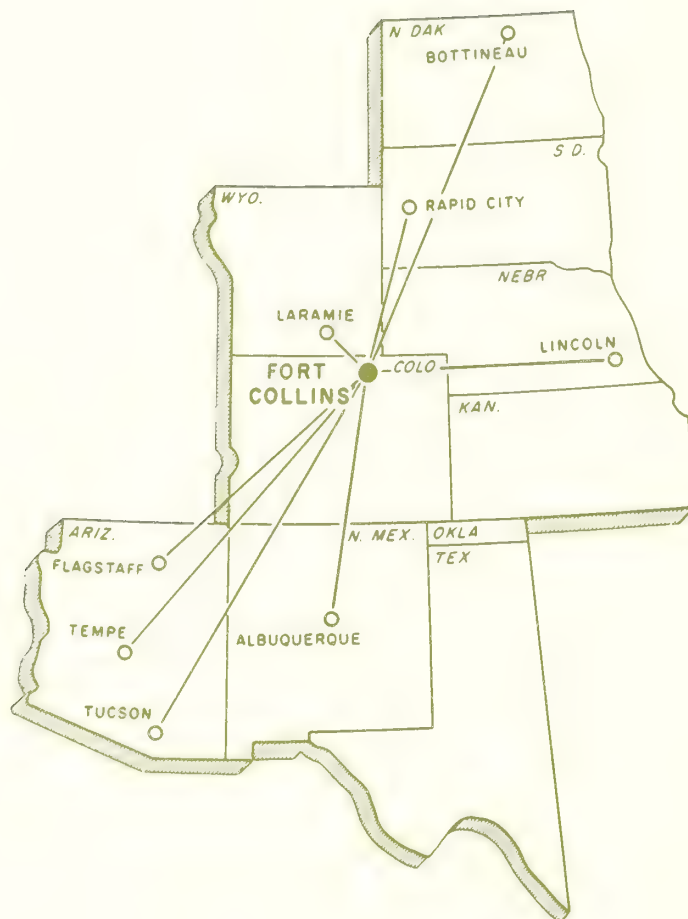
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REFERENCES

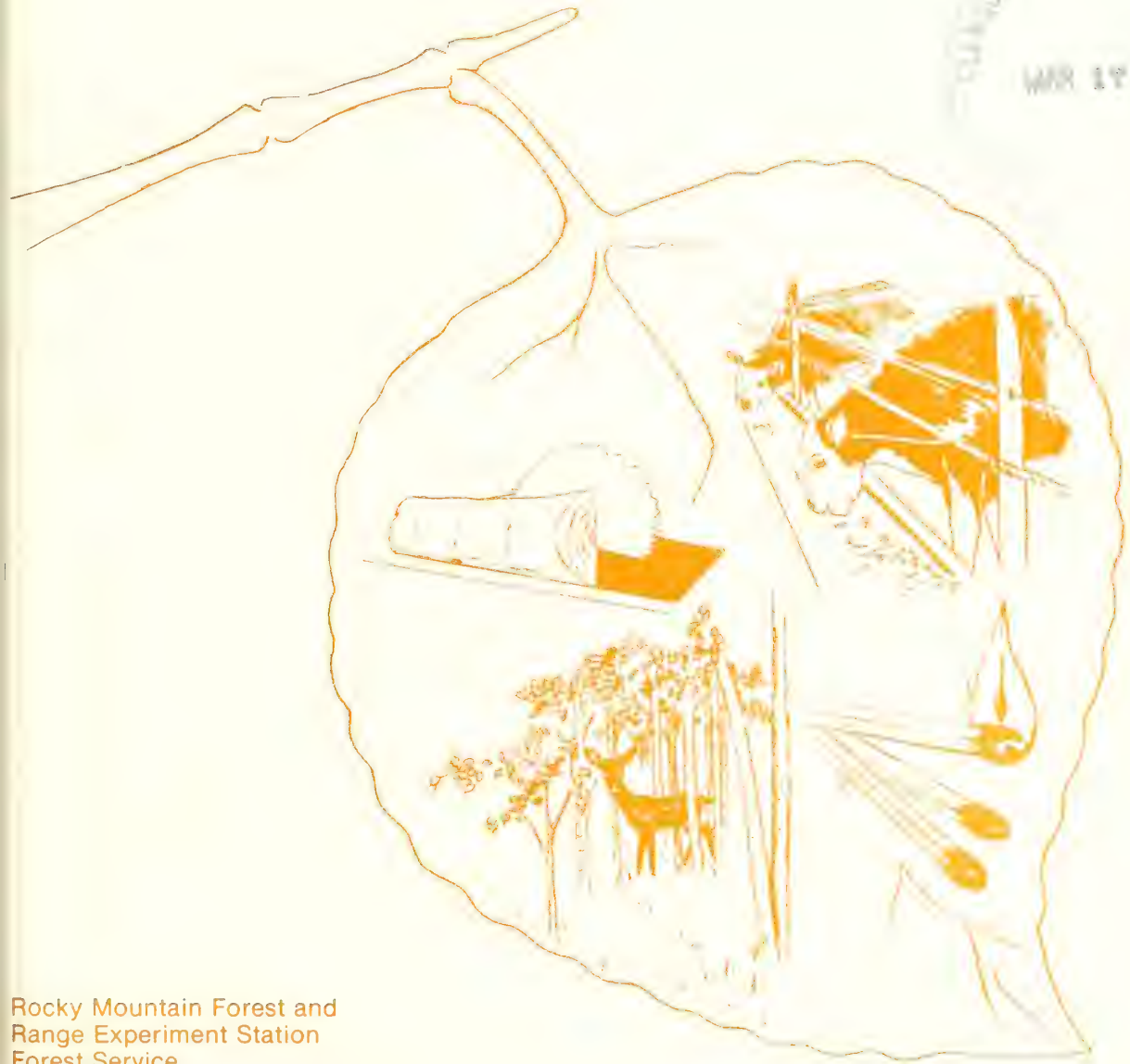
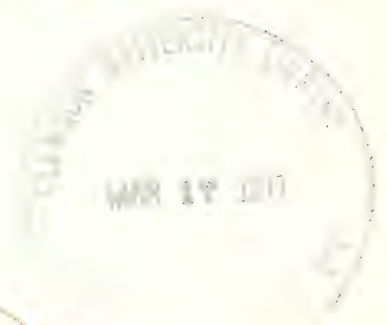
- Behnke, R. J.
1967. Gila and Apache trouts. Rare and endangered species report. Colorado Cooperative Fishery Unit, Colorado State University, Ft. Collins. 11 p. (mimeo)
-
1970. New information on Gila trout, Salmo gilae. Rare and endangered species report. Colorado Cooperative Fishery Unit, Colorado State University, Ft. Collins. 12 p. (mimeo)
- Cope, E. D. and H. C. Yarrow.
1875. Report upon the collections of fishes made in portions of Nevada, Utah, California, Colorado, New Mexico and Arizona, during the years 1871, 1872, 1873 and 1874. Rept. Geog. and Geol. Expl. and Survey West of the 100th Merid. (Wheeler Survey) 5:635-703.
- Jordan, D. S. and B. W. Evermann.
1896. The fishes of North and Middle America, part 1. Bull. U. S. Nat. Mus. 47:1240 p.
- Miller, R. R.
1950. Notes on the cutthroat and rainbow trout with the description of a new species from the Gila River, New Mexico. Occ. Pap. Mus. Zool. Univ. Mich. (529). 42 p.
-
1972. Classification of the native trouts of Arizona with the description of a new species, Salmo apache. Copeia 3:401-422.



Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains

Proceedings of the Symposium

September 8-9, 1976
Fort Collins, Colorado



Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

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1976. Utilization and marketing as tools for aspen management in the Rocky Mountains: Proceedings of the symposium. USDA For. Serv. Gen. Tech. Rep. RM-29, 120 p. Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo. 80521.

Uncontrolled wildfire, which used to assure regeneration of Rocky Mountain aspen, is no longer socially acceptable. Harvesting is therefore necessary to prevent this unique forest type from reverting to coniferous forest. The status of our knowledge about utilization as a tool in aspen management is summarized in 33 papers in five areas: perspectives on Rocky Mountain aspen resource, aspen ecology and harvesting responses, market opportunities and limitations, research advances in aspen utilization, and applying research information to aspen management decisions.

Keywords: Aspen management, aspen symposium.

**Utilization and Marketing
as Tools for Aspen Management
in the Rocky Mountains**

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Fort Collins, Colorado**

Sponsored by:

*Rocky Mountain Forest and Range Experiment Station
Forest Products Laboratory
Intermountain Forest and Range Experiment Station
Forest Service, U.S. Department of Agriculture*

Acknowledgments

The symposium sponsors agreed early last year that such a meeting would be a fitting way to sum up the results of their joint 18-month study of Rocky Mountain aspen utilization opportunities. It could not have materialized, however, without the generous support and participation of a number of other organizations and individuals. I want to extend my warmest thanks to everyone who helped make this venture succeed.

For developing the program and recruiting the speakers and moderators, I am indebted to the Program Committee headed by Eugene M. Wengert, now of Virginia Polytechnic Institute and State University, but formerly with the Forest Products Laboratory, stationed at the Rocky Mountain Station.

Many people in the State and Private Forestry and Research Branches of the U.S. Forest Service contributed significantly by notifying potentially interested organizations and individuals and publicizing the symposium in the press, by arranging for pleasant and commodious facilities, and by editing and publishing these proceedings. William B. Wilcox of the Colorado State Forest Service was particularly helpful in making arrangements.

In addition to the individuals who served on the planning and implementing committees, I want to recognize the following organizations that cooperated with the sponsors in presenting the symposium:

Colorado State Forest Service

Colorado State University
College of Forestry and National Resources

New Mexico Department of State Forestry

State of Utah Forestry and Fire Control

USDA Forest Service, National Forest
Systems, Regions 2, 3, and 4

USDA Forest Service, State and Private
Forestry, Regions 2, 3, and 4

Finally, let me express my deepest appreciation to each and every speaker for his informative presentation. Quick publication of these proceedings--a major planning goal--depended on the cooperation of the authors in preparing their papers in final form, ready for photo-offset reproduction. The moderators also deserve credit for providing a climate conducive to productive exchanges. The discussions during the symposium were unusually active for so large a group.

Because of the genuine interest and active participation of all of you who attended, the success of the symposium exceeded my expectations. I truly hope that it also met yours.

HAROLD E. WORTH
Symposium General Chairman

[The exceptional culinary products baked by Hal's wife Phyllis also contributed greatly to the congeniality of the coffee-break discussions.--Ed.]

Foreword

The sponsors take great pleasure in making available these proceedings of the symposium on utilization and marketing of Rocky Mountain aspen, held in September. Our intent in organizing the symposium was to explore aspen product potentials as they relate to more intensive management of this species in the West. The symposium also provided an early opportunity to share results of an 18-month research assignment on Rocky Mountain aspen utilization, carried out by Dr. Eugene M. Wengert and supported jointly by the symposium sponsors.

From your response, we are confident that the symposium has contributed significantly to a common understanding of the problems associated with aspen utilization. We also believe it will serve as a springboard for future action to maintain and improve the aspen timber type in the Rocky Mountains.

Aspen forests of the Rocky Mountains have been a much appreciated, but generally neglected, resource. The fall color of aspen groves is an awe-inspiring scenic attraction. Their value for wildlife browse and cover is widely recognized, as is their ability to stabilize soils. Further, wood and fiber products made from aspen contribute uniquely to National needs. In short, aspen forests are a recognized asset to the Rocky Mountains and the Nation as a whole. Unfortunately, there is no assurance that we will continue to benefit at the desired level from this species, unless ways are found to manage it more actively.

Most foresters agree that the key to successful aspen management in the Rocky Mountains is in manipulating the age and density of stands. Nature does this through disease and fire, over long periods of time, and periodi-

cally most aspen stands revert to coniferous forests. Since such uncontrolled natural events are no longer "socially acceptable," man is challenged to simulate their overall effects by intentionally removing timber of various forms and age classes to provide residual stands of the desired composition. But such harvesting is practical only if materials to be removed can be satisfactorily disposed of, which suggests a need to create productive and economic uses. This brings us back to the motivation behind this symposium.

The purposes were to bring available information on western aspen utilization into focus, and to explore possibilities for improving resource management through increased marketing opportunities. Without the promise of economic return, the door will be nearly closed on implementing management options to produce the desired aspen forest types.

Interest and enthusiasm evidenced by symposium participants through their attendance, papers, and discussion convince us that the subject was important and timely. We hope these proceedings will help highlight for participants and others what we now know about utilizing aspen, and what must yet be learned. We also hope that the proceedings will serve as a companion document for the forthcoming publication, *Aspen: Ecology and Management in the Western United States*, by John Jones and Kimball Harper, to be published next spring as a Rocky Mountain Station Research Paper. That report will summarize the biological knowledge required for adequate aspen management and the information needed to design further silvicultural research.



Harold E. Worth, Symposium General Chairman
Rocky Mountain Forest and Range Experiment
Station

THE SYMPOSIUM

SEPTEMBER 8-9, 1976

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Panel I.
Perspectives On Rocky Mountain Aspen Resource

Moderator: Eugene M. Wengert

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Perspectives On Rocky Mountain Aspen Resource: An Overview¹

Eugene M. Wengert^{2/}

Abstract.--The Rocky Mountains have more aspen sawtimber than the Lake States, yet the species is not managed for the fiber it can supply. Increasing demand for wood fibers and increasing management activities will result in increasing utilization of aspen.

INTRODUCTION

Aspen (Populus tremuloides Michx.)^{3/}, also commonly called "popples", "poplar"^{4/}, "quaking aspen", and "quaky", is the most widespread species in North America, stretching from Mexico to the Arctic Ocean, Maine to California (Fig. 1). The range is controlled by adequate moisture levels and cool summer temperatures.

Important commercial concentrations of aspen exist in Northeastern United States, the Great Lakes area, central portions of Canada, and in the Central Rockies. In the Central Rocky Mountains, commercial aspen is generally confined to elevations between 7,000 and 11,000 feet. Although aspen is widely distributed in the Rockies (Fig. 1), important commercial sawtimber concentrations are limited to North central and Southwestern Colorado, Northern New Mexico, and South central Utah.

^{1/}Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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^{3/}In some geographic areas "aspen" includes P. grandidentata Michx., and P. balsamifera L. (commonly called big-tooth aspen and balsam poplar respectively). In the Rockies, the only significant aspen species is P. tremuloides Michx.

^{4/}Poplar in the eastern U.S. lumber trade can also refer to yellow-poplar (Liriodendron tulipifera L.).

Aspen is extremely important in the overall resource/land use picture in the Rocky Mountains. It is extremely beneficial for watershed improvement, soil building, and wildlife forage, as well as for recreational uses and scenic beauty. As a generalization these preceeding benefits are the management objectives for the species. Unlike the Lake States, then, the aspen resource in the Rocky Mountains is not managed directly for the fiber it can potentially provide for wood products. And yet, aspen in Colorado has an annual volume increment of 120 board feet per acre (Miller and Choate 1964), well above ponderosa pine, but below Douglas fir. Further, the Rocky Mountains have more sawtimber volume (DBH 11-inches and greater) than the Lake States (Table 1). Colorado has 17% more sawtimber volume than Michigan, 32% more than Minnesota, and 49% more than Wisconsin.

In terms of acreages, the Rocky Mountain States have 4.1 million acres of aspen-type, commercial forest land (CFL) (Green and Setzer 1974).

	Aspen-type Acreage	Commercial Forest Land in Aspen-Type
State	(Acres)	(%)
Colorado	2,288,900	25
Utah	1,105,300	31
New Mexico	346,100	6
Wyoming	187,900	6
Arizona	89,900	2
Idaho	60,200	0
Montana	44,700	0
Nevada	6,500	5
TOTAL	4,129,500	

This is only 31 percent of the aspen CFL in the Lake States (Minnesota, Wisconsin, and Michigan).

However, aspen-type occupies a significant part of the commercial forest land in the Rocky Mountains. In Colorado, aspen-type acreage is 25 percent of the total commercial forest land; in Utah, 31 percent (occupying more land than any other forest type); and in New Mexico, 6 percent. Sixty-five percent of this aspen-type acreage is public land.

In recent years the importance of managing aspen and maintaining the species as an important component of our Rocky Mountain forest has been recognized.

Indeed, many of the benefits obtained from the species cannot be achieved without proper management.

Table 1.--Net volume of aspen growing stock and sawtimber on commercial forest land, 1970

	- - - - - GROWING STOCK - - - - -		- - - - - SAWTIMBER - - - - -	
	Aspen Volume	Aspen Volume Compared With Total Growing Stock Volume	Aspen Volume	Aspen Volume Compared to Total Sawtimber Volume *
	million (cu.ft.)	(%)	million bd.ft. (1/4-in. INT rule)	(%)
ROCKY MOUNTAINS				
Colorado	1,807.4	15	3,142.4	8
Utah	1,038.5	22	1,574.4	7
New Mexico	600.9	9	1,475.3	11
Arizona	226.1	5	678.7	3
Wyoming	170.3	4	199.4	2
Idaho	68.6	0	117.0	1
Montana	51.4	0	74.1	0
Nevada	12.2	5	21.8	
TOTAL	3,975.4		7,283.1	
LAKE STATES				
Wisconsin	2,159.5	20	2,109.3	11
Michigan	2,257.1	15	2,684.0	9
Minnesota	3,018.2	31	2,387.9	18
TOTAL	7,434.8		7,181.2	

Sources: Green and Setzer (1974) for RM data
Chase et al. (1970) for Michigan data
Spencer and Thorne (1972) for Wisconsin
Spencer (1968) for Minnesota

* Includes softwoods 11" DBH and greater

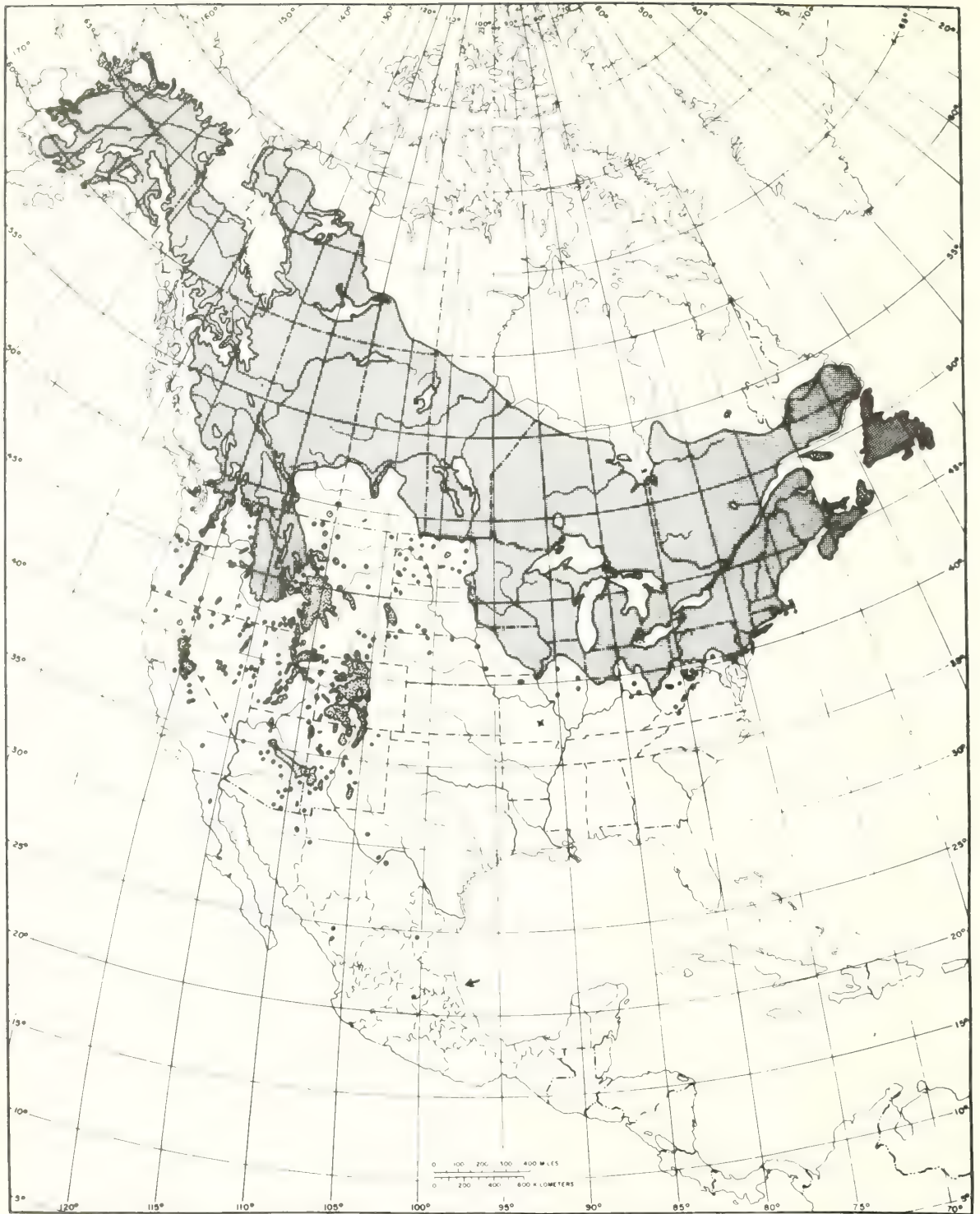


Figure 1.--Aspen distribution in North America (Little 1971).

In the past an important "natural" aspen management tool was wildfire--young aspen, arising from root sprouts, would quickly reforest a burned conifer area. As these aspen sites matured, they frequently would naturally revert back to conifers in 100 to 200 years. However, with the control of wildfire (and with the present cutting and logging practices in the conifers that do not open up large areas) conditions are often unfavorable for large scale aspen regeneration (Schier 1975). Yet, as stated above, it is important to keep the aspen forest as part of the total Rocky Mountain forest in widespread locations. The management tool that is available to do this is aspen wood utilization. By logging aspen in small, cleared areas, the aspen will regenerate and the type can be maintained where and when desired (Jones 1975).

With this rosy picture, it might seem as though the resource is waiting to be tapped. Yet annual usage is below 10 million feet. Frequently, the lack of markets or availability of better species (i.e., conifers) is blamed for this lack of utilization. Indeed this may be part of the problem, but the resource itself also causes some difficulty:

- a) 2/3 of the aspen sawtimber is between 11 and 15 inches
- b) decay becomes significant on poor sites well before commercial size is attained and on good sites shortly after sawtimber size is reached.
- c) aspen is generally scattered in large and small groves interspersed among the conifers increasing procurement and handling costs.
- d) other uses or demands on the resource preclude harvesting
- e) the form of the tree increases harvesting, transportation, and milling costs.
- f) snowfall limits accessibility to three to six months per year

The impact of these items should not be underestimated. Some of these will be discussed in subsequent papers in more detail.

The regional and national demands for fiber also may affect the resource and its utilization...and vice versa. The U.S. Forest Service's analysis, "The Outlook for Timber in the United States," indicates increases in per capita consumption of wood (both in solid forms such as lumber, and in reconstituted forms such as paper) as well as increases in population. The demand in 1970 was 12.7 billion cubic feet; the projection for 2000 is 23 billion. It's projected that roundwood hardwood removals in the Rocky

Mountains will increase from 3 million cubic feet in 1970 to 76 million cubic feet by 2000. Of course, these are only projections but they do indicate the increasing utilization pressure on the resource. And aspen will become a more acceptable species, I believe, because

- (a) the industry is cutting and processing more small diameter timber
- (b) fiber or particleboard mills will become established in the region
- (c) landowners will become more aware of the management needs of the species.

In summary we have a significant aspen resource in the Rocky Mountains. Over the next few decades utilization will become an important management tool for maintaining the resource and its benefits.

LITERATURE CITED

- Chase, C. D. et al.
1970. The growing timber resource of Michigan 1966. USDA For. Serv. Resource Bull. NC-9.
- Green, A. W., and T. S. Setzer.
1974. The Rocky Mountain timber situation, 1970. USDA For. Serv. Resource Bull. INT-10. 78 p.
- Jones, J. R.
1975. Regeneration on an aspen clearcut in Arizona. USDA For. Serv. Res. Note RM-285. 8 p.
- Little, E. L., Jr.
1971. Atlas of United States trees. Vol. 1 Conifers and important hardwoods. USDA For. Serv. Misc. Publ. No. 1146.
- Miller, R. L., and G. A. Choate.
1964. The forest resource of Colorado. USDA For. Serv. Resource Bull. INT-3, 54 p.
- Schier, G. A.
1975. Deterioration of aspen clones in the middle Rocky Mountains. USDA For. Serv. Res. Pap. INT-170. 14 p.
- Spencer, J. S., Jr.
1968. A third look at Minnesota's timber. USDA For. Serv. Resource Bull. NC-1.
_____, and H. W. Thorne.
1972. Wisconsin's 1968 timber resource--a perspective. USDA For. Serv. Resource Bull. NC-15.

Perspectives On Rocky Mountain Aspen Resource: Forest Industry¹

Percy D. Gray^{2/}

Brief History of the Splint Plant in Mancos

In 1944 or 1945 a timber cruise was made in the Mancos Ranger District on the aspen resources. This study was made by an assistant range from the Delta District--a man by the name of Charles Town, now 80 years old and still living in the area. Though retired, he remains interest in the results of the cruise and, of course, the welfare of the match splint plant located in Mancos, more or less as a result of his cruise study. He recalls a man by the name of E. A. Snow was supervisor of the San Juan Forest at that time.

The plant was constructed in 1946 or 1947 by Berst Forster Dixfield Company, Division of Diamond Match Company. Plant began operation in 1947 and shipped splints to Dixfield, Maine and Oswego, New York. Pocket and regular penny boxes of splints were the only square splints produced at this time. Operation was stopped in 1949 because of a large amount of splints.

Plant resumed operation again in 1951 under the name of Diamond Match Company. The Mancos plant was the first to produce the square kitchen match, and these splints were shipped to Oshkosh, Wisconsin, and Chico, California.

Diamond sold the Mancos Plant to Ohio Match Company, Division of Hunt Foods and Industries, on May 1, 1960. Two of our present employees helped on the construction of plant, and others have been with the plant since it started operations.

Plant Location and Processes

The life of the wooden Ohio Blue Tip

^{1/}Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

^{2/}Plant Manager, Ohio Match Company, Mancos, Colorado

match you strike today began 80 years ago in the mountains of Colorado when a little aspen tree took root in the rich soil among the rocks. The tree grew until it reached a height of about 40 feet and became mature for harvesting under the planned forest programs of today.

At the Ohio Match sawmill in Mancos, Colorado, the tall, white aspen is transformed into match sticks. The tree is cut into bolts about two feet long, the bark is stripped off, and the bolts are fed into a veneer lathe which cut around and around their circumference (just like you'd peel an apple) and turns them into thin, continuous sheets of wood.

Next a larger chopper slices the sheets into thousands of precision made sticks. The sticks then pass through a liquid (ammonium phosphate solution) which treats them so they won't glow after being extinguished, and they are ready for delivery to the factory at Wadsworth, Ohio.

We have recently completed 2,560 days without a lost-time accident in our Mancos Plant--nearly six years.

Quality

Since the Consumer's Safety Commission in Washington has focused attention on the match, we have furnished information and help towards setting new safety standards. This has proved frustrating to us in Mancos at times because, in effect, break strength standards were raised from six pounds to eight pounds four ounces on kitchen splints while aspen harvesting utilization standards were raised to one-third good on a saw log base rather than a match bolt base on the United States Forest Service aspen sales. You all know what kind of a problem then is presented when we try to chuck a punky and rotten centered match bolt in our veneering lathes.

Silvicultural requirements on our present aspen sale are costing us about eight dollars slash reduction on a program that I question the value of. I feel industry is paying for a lot of experimental unknowns. With spiraling

costs, the economics of producing a product such as we do has become a major thing. Check the price of a box of matches at your friendly grocer--it still is very reasonable.

Economics

Environmental and aesthetic costs are proportional much too high at this time, weighed against the end product. We are dealing with a low value timber resource and installing high priced hardware in trash fences and a road system much too high in standard to warrant the end product.

Road costs now are seven to eight dollars for our timber resource valued at one dollar!

Only fifty per cent of the logs arriving in our log yard can be utilized in our end product. The cull types arriving must be sold to other users such as the excelsior and the mine prop and furniture people such as Western Timber and Development Company that broker this fifty per cent we can not use. We are very fortunate to have Western Timber and Development working so closely with us in this utilization.

Changing harvesting standards on the new aspen sale contracts do not recognize the match

bolt standard that this plant was built and operated on in Mancos since its conception. Aspen sales recently have only been presented on a saw log basis. For those of you who have heard the match bolt standard, it is as follows:

A match bolt shall be considered as 24 inches long and is merchantable if it contains no more than 8 inches of surface length of defect determined by adding the sum of the knot diameters, length of seams, dry faces, and decay: Provided, that rot of any kind in the center of a bolt shall cause the bolt to be classed as unmerchantable if it exceeds 2 inches in diameter in bolts less than 10.0 inches in diameter, or if it exceeds 4 inches in diameter in bolts 10.0 inches and larger in diameter. Vs. our well known saw logs standards using a "1/3 good" standard.

Designated cutting at that time was as follows:

All live aspen trees 10.0 inches and larger in diameter at a point 4-1/2 feet above the ground, merchantable as defined, are designated for clear-cutting: Provided, that cutting in aspen stands 10 acres and larger in area which contain an average of less than 1,500 board feet of merchantable timber per acre will not be required.

Aspen In Perspective In Colorado¹

Robert S. Mathison^{2/}

Abstract.--The distribution of the aspen tree in Colorado and Wyoming is significant. To relate aspen in perspective to other species of trees is to realize that 1/3 of the forested land in Colorado supports aspen. The potential as a timber resource is appreciable. Approximately five million board feet are harvested annually in Colorado from a total harvest of 285 million board feet, all species.

Good Morning - I am excited about being involved in this symposium; not so much for what I'm going to contribute but rather, the agenda tells me that I am going to experience two days with many interesting panel discussions. I will present data on the Aspen's vastness, that is to say, area, productivity, and utilization. This will be a part of the many parts that go into making up the total story that will be developed over the next two days.

Aspen causes a migration of the urban residents to the mountains each fall, to view the aspen in color. For a week or ten days each September, the spectacular beauty of aspen is the subject of pictorial specials on TV and in the newspapers. Even transcontinental airline passengers can appreciate aspen in color as almost one-third of the forested land in Colorado turns to gold. It is truly beautiful.

Extent

In spite of short-lived popularity each fall, for the balance of the year, aspen is virtually ignored. Its potential as a timber resource is seldom discussed. It is therefore very timely and critical that many of us acquire an understanding of the aspen resource. Time is becoming critical for many of our aspen stands in that they are beginning to deteriorate, and this deterioration will increase significantly in the next 40 years.

Of the nine million acres (CFL & NON-CFL) support aspen. Two-thirds of this is on National Forest lands. The Shoshone, Bighorn, and Medicine Bow National Forests in Wyoming contain an additional one hundred thousand acres of aspen. Our aspen stands are classified into the unregulated^{3/} land classification component, with the exception of 2,500 acres on the San Juan National Forest which is in the standard and special component (268,900 acres of aspen type). The preponderance of our aspen stands are in Colorado; therefore, the balance of this presentation will be limited to the aspen resource in Colorado.

Productivity

Because aspen stands often contain a high proportion of small, crooked trees and are highly susceptible to a variety of diseases, aspen has sometimes been considered a weed species. Frequently overlooked is the capacity of this species to produce sawlog-size trees in a relatively short time: 250,000 acres of aspen are classified as capable of producing 85 cubic feet (approximately 390 board feet) per acre per year. Only the spruce-fir type has comparable productivity. Although aspen may be found at both the upper and lower limits of tree growth, the most productive sites are located on Western slope forests between 7,000 and 9,000 feet in elevation. Aspen also shows excellent growth where it occurs in varying mixtures with spruce and fir at elevations above 9,000.

^{1/} Paper presented at the Symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

^{2/} Silviculture and Timber Management, USDA Forest Service, Region 2, Lakewood, Colorado.

^{3/} Forest lands suitable and available but not organized for timber production under sustained yield principles, where timber harvest is permissible but not a goal of management.

Perspective

Of the nearly 3 million acres, less than a half million acres of the aspen type are in the sawtimber size class. Therefore, even though aspen occupies almost a third of the forested area, it represents only 15% of total commercial cubic foot volume and 6% of the commercial board foot volume. The volume of this resource in Colorado is 3.7 billion board feet or 1.9 billion cubic feet.

I have already mentioned the value of the aspen resource for recreation and esthetics. In addition, the aspen type produces abundant forage for domestic livestock and wildlife. Its value as a timber resource has been barely tapped.

Utilization

About five million board feet are harvested annually, which is approximately 2% of Colorado's harvested volume. The majority of this volume is utilized as matchstock. The balance is manufactured into boards, paneling, excelsior, and speciality products. During the Viet Nam conflict, for example, a plant at Hotchkiss utilized two million board feet annually to manufacture disposable pallets. One contributing factor to this low level of utilization is the relative low quality. Many stands consist of small trees of poor form. The horseshoe fungus is a serious pathogen of the species. Even in its incipient stage, this disease materially reduces wood strength.

Generally, disease is more prevalent in overmature aspen stands just as it is in other species. Much of the aspen existing today invaded areas disturbed by extensive fires, mining, ranching, and railroad building activity in the late 1880's. These stands are now at or beyond the rotation age of 80 years. As stated earlier, without management (utilization through harvest or controlled burning of stands), the older aspen stands will continue to deteriorate and many will be invaded and occupied by the more tolerant conifers or by shrubs and grasses.

A Projection

The 2,386 million acres of aspen in Colorado are a resource widely used for esthetics, recreation, wildlife, and grazing of domestic livestock; none of which will significantly aid in perpetuating the stands. The suitability of our aspen stands for these purposes will continue to diminish as our stands continue to deteriorate and are replaced by other vegetation.

The utilization of aspen for wood products will increase significantly over the next 10-20 years as research findings are implemented and resulting consumer demands rise.

These increased demands for aspen as a wood product should peak in terms of time as our aspen stands disappear from the scene.

Aspen Resource In The Southwest¹

Darrell W. Crawford^{2/}

Abstract.--There is a relatively large source of unused aspen in the Southwest. If markets can be developed, there are challenging opportunities to utilize more of this fiber. Most aspen in the Southwest is classified in the marginal component because of steep slopes, accessibility and low market values. To meet the logging constraints of this component is a real challenge to prospective purchasers. However, commercial opportunities are feasible on the Carson, Santa Fe, Apache and Kaibab National Forests.

The aspen type in the Southwest is extremely valuable for aesthetics and wildlife habitat, but to maintain the type and provide habitat harvesting is essential. The acres of aspen type are declining because of the absence of fire and conifer understories taking over the site. Because of past tree selection and present shelterwood cutting methods the occurrence of aspen in ponderosa pine and mixed conifer is also on the decline.

Maintaining the aspen type and managing for its highest values are dependent on being able to harvest aspen and harvesting aspen is dependent on having a market for products. Therefore, the critical factor in the Southwest is development of aspen fiber markets.

Aspen (*Populus tremuloides*) grows under a great variety of conditions and can be found in small stands on most National Forests in the Southwest. In the Southwest Region of the U. S. Forest Service (New Mexico and Arizona) there are approximately 180,000 acres of pure aspen stands and 350,000 acres of mixed conifer stands that include aspen. This 530,000 acres represents approximately nine percent of the commercial forest lands in the Southwest.

Using the Forest Service Standard timber Land Classification the 180,000 acres of pure aspen stands are classified as twelve percent standard component, three percent special com-

ponent, eighty-one percent marginal component and four percent unregulated component. The majority of aspen is placed in the marginal component (81%) because of steep slopes, poor accessibility and low market value.

In the Southwest the highest value placed on aspen is for its contribution to the scenic beauty of the landscape. Aspen is a very aesthetically pleasing tree and contributes greatly to the variety of the forests. The velvet green leaves in spring, bright yellow leaves (at times tinged with red) in the fall and white bark that contrasts with that of the conifers is vital to the scenery in a Region dominated by pure conifer forests. This high value placed on the scenic qualities of aspen does not mean that it cannot be harvested and utilized to benefit man. In fact, just the opposite, it must be harvested to obtain regeneration and maintain healthy stands that will provide the aesthetic values in the future.

The distribution of aspen within the Southwest Region finds about seventy percent

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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of the stands in Northern New Mexico on the Carson and Santa Fe National Forests, nine percent in central and southern New Mexico and 21 percent in Arizona distributed about equally on the Apache, Coconino and Kaibab National Forests. Commercial harvest of aspen is considered economically feasible in Northern New Mexico, on the Apache portion of the Apache-Sitgreaves National Forest and on the North Kaibab portion of the Kaibab National Forest. Each of these units requires separate discussion as they do not lend themselves to one commercial operation because of distance separating them.

The Carson and Santa Fe National Forests of Northern New Mexico offer the greatest commercial potential. There are 121,000 acres of aspen type of which approximately one half is presently accessible. The annual potential yield is 6.5 MMbf of sawtimber and 4,600 cords of poletimber. The stands are of average quality with considerable heart rot at the lower elevations. The volume is primarily located in the marginal component because of logging constraints on steep slopes and no existing markets. There are small amounts of studs, wall paneling, excelsior and corral poles being produced. There is sufficient aspen to support a small sawmill operation, but the future utilization of the aspen potential in Northern New Mexico probably depends on the development of a pulpwood market.

The Apache portion of the Apache-Sitgreaves National Forest has 15,100 acres of aspen type classified in the marginal component. Most of these acres are of good quality aspen in the seventy year age-class. There has been virtually no market for aspen on the Forest, but inquiries have increased on the availability of aspen for poles, shakes, excelsior and pulpwood.

The long term Colorado Plateau Pulpwood Sale (terminates in 1989) purchased by Southwest Forest Industries provides for 252,000 cords of aspen as an optional species. However, the Southwest Forest Industries pulpwood plant at Snowflake, Arizona is presently not set up to process aspen. As the demand for fiber increases, the purchaser may become more receptive to the aspen option. A potential for Aspen sawtimber harvest on the Apache National Forest does exist, but presently the annual potential yield is established at 5,300 cords.

The Kaibab National Forest has 15,200 acres of pure aspen (97% is on the North Kaibab) of which 14,200 acres are classified in the standard component, available, accessible and of average aspen quality. The annual potential yield is 4.8 MMbf or 10,977 cords of sawtimber and 8,938 cords of poletimber. The present outlook is that aspen is extremely valuable for aesthetics and wildlife, must be harvested in order to manage for aesthetics and wildlife, and that aspen will become an important producer of wood fiber. Aspen represents nine percent of the wood fiber on the North Kaibab, but no market presently exists.

REFERENCES

- Apache Timber Management Plan
Approved December 16, 1975
- Carson Timber Management Plan
Approved April 4, 1975
- North Kaibab Timber Management Plan
Approved June 29, 1972
- Santa Fe Timber Management Plan
Approved July 10, 1975

Aspen Potential — A Land Manager's Viewpoint¹

Bruce B. Hronek^{2/}

From a land manager's viewpoint, the management of aspen has been lacking. However, the potentials of aspen as a viable and meaningful species that will contribute much to the forest environment and economics is both possible and practical.

Aspen, as a tree or part of an ecotype, has always been a very interesting subject for discussion among land managers. We typically like to discuss its merit as an overstory for wildlife, as a viable area indicating soil conditions conducive to good grazing, as a scenic landscape in its mottled patterns, as an indicator of stable watershed conditions, and as a place for people to enjoy recreation experiences. But, like the weather, few are concerned about management direction, economics, or its potential. What most Western and Rocky Mountain land managers do not want to talk about is management of aspen ecotypes for their multiple benefits, including wood products for a growing economy. Many who talk of managing aspen for the totality of its ability to provide both a viable forest environment and as an economically feasible wood are generally considered heretics or, at best, troublemakers.

Research and other literature reviews seem to indicate we may have been going in the wrong direction in managing aspen, especially in the areas along the Wasatch Front in Utah, where watershed policy has protected these areas from cutting and intensified all fire protection. We are now getting invasion of the sites by conifer types and replacement, to a great extent, of what were traditional aspen stands by other species. The aspen is getting old, generally over 80 years of age, with well defined signs of deterioration (Alder 1970).

^{1/} Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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Aspen is the most widespread deciduous type in the Western United States. It dominates over 6.3 million acres of forest in the Rocky Mountain-Great Basin Region. The majority of this acreage is found in Colorado (over 3.0 million acres) and Utah (over 1.3 million acres). Wyoming and southern Idaho each have over one-half million acres; and New Mexico, 0.4 million acres. Nevada, Arizona, and western Montana make up the remainder (Choate 1965) (Green and Setzer 1970).

A few facts should be brought out concerning the management aspects of aspen and some of the things we should be concerned with in our establishment of aspen policy.

Aspen is esthetically desirable. The texture and variation in aspen stands make it desirable both as a foreground and a background vegetation. The various shades in the fall make it especially pleasing in a landscape. With few exceptions, it has esthetic characteristics superior to other tree species native to the Rocky Mountain-Great Basin Region.

Aspen grows rapidly and is one of the fastest growing tree species in the Intermountain West. The most common method of reproduction is through root sprouting, thus reducing costs and the uncertainty of regeneration (Brinkman and Roe 1975). Cutting appears best during dormant periods because of better opportunities for sprouting (Strothmann and Zasada 1974). Rotation is 60 to 80 years, as compared to 120 years for most other species in the Great Basin.

Aspen is fire resistant. Conifers, particularly white fir, are slowly replacing aspen in many areas. Conifer is especially susceptible to large fire situations (Gurell and Loope 1974). Replacement of aspen with

conifer is resulting in increased fire hazards, especially along those critical watersheds that are so vital to the Wasatch Front communities. Fires that do occur naturally in aspen appear to be smaller in size than conifer fires.

Aspen is also an effective watershed cover. Aspen, through canopy intercession and general abundance of understory vegetation, provides for very effective watershed conditions. The flood history of aspen stands compared to conifer stands indicates aspen is a superior species. Studies show aspen as using less water than conifer on the same site on a year round basis (Johnston and Doty 1972).

Aspen creates a superior wildlife habitat. Wildlife biologists indicate aspen provides an optimum habitat for a variety of small and large animals. It is superior to conifer in the variety of wildlife feeding and nesting in its environs (Morgan 1969).

Most aspen stands provide high forage production. The available vegetative cover under the aspen on the Uinta National Forest in Utah averages 2,100 pounds dry weight per acre, compared to 300 pounds dry weight per acre for conifer. This information is derived from range environmental analysis data. The obvious ramifications of understory production lie within the needs of the livestock industry and the National emphasis in red meat production.

An objective view of aspen must also point out some limitations. The species' size and height characteristics have resulted in little interest from the timber industry and little public acceptance of aspen as a viable building material. The exception is pulpwood use in the Lake states. A limited, local market for aspen as mine washers and pallet materials is developing in Utah, but only a relatively small demand exists at this time. Its susceptibility to bark carving and lack of resistance to disease makes it somewhat undesirable as a recreation site overstory.

Some misconceptions concerning aspen should also be dispelled. Aspen does not utilize excessive amounts of water through evapotranspiration processes. Aspen is important both as a watershed protection species (especially in regard to intensive summer rainfall common to the mountain west) and as a vegetative soil type that allows good regimen streamflow (Johnston and Doty 1972).

With all these items in mind, allowing the aspen acreage to shrink or be reduced in vigor by default or ignorance seems to be ill advised, considering the many positive aspects of having a viable aspen forest. As stated

previously, the present policy along the Wasatch Front prohibits the cutting of any trees to protect the vital watersheds. With the large, adjacent populations, controlled individual free-use firewood permits could be an effective management tool along the higher populated Wasatch Front area. Well conceived, commercial timber sales may also be a vital management tool.

It is exciting for the land manager to recognize some of the new research information that has been and is now being developed. The Great Basin and vicinity is considered the center of optimum development of aspen in North America and is also an important range cattle producing region (Morgan 1969). The possibility of using aspen bark and other aspen materials as live-stock feed offers some potential, without using vital feed grains needed to feed world populations (Baker, Miller, and Satter 1975).

In conifer forest management, one of the real problems at the present time is regeneration of the stands and the exceptionally high costs of planting in poorly stocked, burned, and cutover stands.

Aspen provides an exciting alternative to the land manager because it reproduces vigorously by means of root suckers. These root suckers are produced from sucker buds on the shallow lateral roots, usually from those that are within 3 or 4 inches from the soil surface. Some research indicates that aspen should be cut on a relatively short rotation because sucker reproduction is strongest in the mid-years of its normal lifespan and during a period immediately after cutting, when soil temperatures are held constant and there is abundance of strong light to produce vigorous development of young suckers (Brinkman and Roe 1975).

Changes in both policy and attitude are needed if we want to continue in creative forestry. Aspen's silvicultural characteristics demand it be recognized on its own merits, not the traditional "weed species-noncommercial" attitude of the past. Recognizing the limits placed on the products by economics and public acceptance, planning for the future is important now. Our experience has shown us that "weed species" of a few years ago are a vital part of our economy today. Through recognition of potentials, planning, research, and effective management, aspen can offer the economy and the consumer much in the future.

LITERATURE CITED

- Alder, Guy Michael
1970. Age Profiles of Aspen Forests in Utah and Northern Arizona, Thesis, M.S., Department of Biology, University of Utah.

- Baker, Andrew J.; Millett, Merrill A.; and Satter, Larry D.
 1975. Wood and Wood-based Residues in Animal Feeds, Forest Products Laboratory, Forest Service, USDA, Technical Article 6.
- Brinkman, Kenneth A. and Roe, Eugene I.
 1975. Silvics and Management, Forest Service, USDA, Agricultural Handbook No. 486.
- Choate, Grover A.
 1965. Forests in Utah, Intermountain Forest and Range Experiment Station, Forest Service, USDA, Research Bulletin, INT-4.
- Green, A. M. and Setzer, T. S.
 1974. The Rocky Mountain Timber Situation 1970, Intermountain Forest and Range Experiment Station, Forest Service, USDA, Research Bulletin INT-10.
- Gurell, G. E. and Loope, L. L.
 1974. Relationships Among Aspen, Fire, and Ungulate Browsing in Jackson Hole, Wyoming, Forest Service, USDA.
- Johnston, Robert S. and Doty, Robert D.
 1972. Description and Hydrologic Analysis of Two Small Watersheds in Utah's Wasatch Mountains, Intermountain Forest and Range Experiment Station, Forest Service, USDA, Research Paper INT-127.
- Morgan, M. D.
 1969. "Ecology of Aspen in Colorado," The American Midland Naturalist.
- Strothmann, R. O. and Zasada, Z. A.
 1957. Silvical Characteristics of Quaking Aspen, Lake States Forest Experiment Station, Forest Service, USDA, Station Paper No. 49.

Panel II.
Aspen Ecology And Harvesting Responses

Moderator: Walter F. Mueggler

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Type Variability And Succession In Rocky Mountain Aspen¹

W. F. Mueggler^{2/}

Abstract.--Most of the 6 million acres of aspen lands in the West occur in the Central Rocky Mountains. The ability of western aspen to occupy a wide variety of sites, the great genetic diversity among clones, and the role of aspen as both a dominant successional and stable species severely complicate management. Such ecological and genetic diversity results in considerable variability in both resource production and potential response to management. Progress in classifying the ecological variability of aspen lands is slow; useful partitioning of genetic diversity is nil.

INTRODUCTION

Quaking aspen (*Populus tremuloides* Michx.) occupies a unique position as a dominant forest tree. It is the most widely distributed tree in North America; the aspen type is recognized for its multiple values of wood, livestock forage, wildlife habitat, and esthetics; yet in the West it has received very little management or research attention. Lack of interest in the past probably stems from the weak demand for aspen wood products, which is certain to change with time. Demands for all of the multiple products obtainable from our aspen lands will undoubtedly increase. Already our resource managers are facing the problems created by the broad range of environmental conditions where the type occurs and by the genetic diversity of aspen itself, both of which severely complicate development of reliable management practices.

DISTRIBUTION

Aspen extends across the North American continent from Labrador to Alaska, and as far south as Mexico (Little 1971). It occupies approximately 6 million acres (2.5 million ha)

of the western United States. The most extensive stands in the West are found in the Central Rocky Mountains. Colorado and Utah alone contain over 4 million acres (Jones and Markstrom 1973). Although widely distributed elsewhere in the West, in these areas aspen is usually confined to small, isolated stands or rather narrow, transitional zones between conifer forests and grasslands.

Aspen grows under a wide variety of environmental conditions. However, its range in the Rocky Mountains appears to be related to cool, relatively dry summers and winters with abundant snow. Summer temperatures above 90° F (32° C) are rare, while winter temperatures below 0° F (-18° C) are common. Annual precipitation ranges from about 16 inches (40 cm) to over 40 inches (100 cm), mostly in the form of a deep winter snowpack which, upon melting, recharges the soil with moisture sufficient to meet most of the water requirements of aspen during its period of active growth.

Aspen grows at elevations ranging from less than 3,000 feet (923 m) in northerly latitudes to over 10,000 feet (3,077 m) in the more southerly latitudes. In Colorado and Utah, aspen commonly occurs in an elevational belt between about 6,500 feet (2,000 m) and 10,500 feet (3,230 m). Aspen is found on a wide variety of soils ranging from rocky talus slopes to deep, heavy clays. The better stands, however, are usually found on deep, loamy soils.

GENETIC VARIABILITY

Aspen in the Central Rocky Mountains is recognized as a probable climatic race distinct

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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from that extending across Canada and into the Lake States. The Rocky Mountain aspen is designated by the varietal name *Populus tremuloides* var. *aurea*. Great and unclassified variability exists within variety *aurea*, which confuses attempts to develop precise management guides.

Anyone familiar with aspen soon becomes aware of the striking variability in growth form and in coloration of different clones. The almost exclusive vegetative mode of reproduction gives rise to genetically identical trees within a clone (Barnes 1966), which emphasizes the visual impact of phenotypic differences between clones.

Clones of eastern aspen vary markedly in stem form, branching habit, height and diameter growth, leaf morphology, leaf flushing, fall colors, leaf drop, and susceptibility to disease (Barnes 1969; Wall 1971). Similar phenotypic variability apparently exists in western aspen. Barnes (1975) sampled over 1,200 clones from Colorado to British Columbia, and by multivariate analysis of only leaf, bud, and twig characteristics demonstrated variation among 24 basic populations. He found a gradient in leaf characteristics from southern Utah to northern Idaho and Montana. Tew (1970) observed that the nutrient content of aspen foliage differed appreciably among clones of western aspen. For example, clonal differences in protein content ranged from 11.8 to 16.2 percent, suggesting considerable clonal variability in the value of aspen suckers for wildlife browse. It is very likely that growth rates, longevity, and other important but obscure physiological processes also differ markedly among clones. Such clonal variability might well affect the potential of different clones for producing wood products as well as the clone's response to harvesting and other management practices.

Unfortunately, progress in partitioning genetically similar strains within the Rocky Mountain variety of quaking aspen has been minimal.

SERAL VS. STABLE ASPEN

Aspen has generally been regarded as a fire-induced successional species able to dominate a site until replaced by less fire-enduring but more shade-tolerant and environmentally adapted conifers. The extensive stands of aspen throughout the Rocky Mountains are usually attributed to repeated wildfires. This is no doubt true for many of our aspen lands, as evidenced by aspen's relatively rapid replacement (within a single aspen generation) by conifers upon curtailment of fire. In areas of optimum aspen development in western Colorado and

central Utah, however, conifer invasion can be so slow that well over 1,000 years of fire-free conditions may be required for aspen stands to progress to a conifer climax.

The uneven-age distribution of aspen trees in some stands suggests that under certain conditions aspen can be self-perpetuating without requiring a major rejuvenating disturbance such as fire or cutting. From a management standpoint, these relatively stable stands of aspen can be considered *de facto* climax. We expect them to remain dominated by aspen in the foreseeable future.

The successional status of aspen on a given area and the ability to recognize seral versus stable stands have considerable management significance. Obviously, we should be wary of planting conifers on stable aspen sites. Also, we must be alert to the need for removing conifers from seral aspen sites if we wish to maintain aspen dominance.

Even though we are reasonably certain that both stable and seral site conditions exist, progress in developing criteria that define environmental conditions indicative of seral and stable aspen communities has been minimal. Harper (personal communication) suggests that the rate of conifer succession might be predicted from knowledge of understory species. For example, on the Wasatch Plateau in Utah, Oregon grape and myrtle pachistima are indicative of areas subject to rapid invasion by conifers, but mountain snowberry and red elderberry indicate a relatively stable aspen community. Harper found that although seral aspen stands appear to be associated with sandstone soils on the Wasatch Plateau, they are associated with basaltic soils on the Aquarius Plateau and with granitic soils in the LaSal Mountains.

As yet, the most valid general indicator of a seral aspen situation appears to be the presence of conifers, which suggests active replacement of the aspen overstory by a more shade-tolerant tree. Mere presence of conifers, however, is not the infallible indicator of a seral condition that one might suppose. Occasional conifers can be found in a basically stable aspen community because of a highly unusual and temporary combination of circumstances favoring conifer establishment. In such cases, a stable aspen community might contain a few scattered, uneven-aged conifers but lack subsequent conifer reproduction. Presence of a multiaged conifer understory is generally reliable evidence of a seral aspen site.

In addition to replacement by conifers, aspen can also be replaced by shrublands or grasslands. Such replacement usually occurs on sites not suited for the establishment and growth of

conifers and where aspen fails to regenerate. Regeneration can fail when apical dominance prevents suckering during gradual deterioration of the clones (Schier 1975). Where suckering does occur in a decadent clone, continued heavy browsing of sprouts by deer, elk, or livestock can prevent successful regeneration and cause conversion to shrublands or grasslands.

TYPE VARIABILITY

The ability of aspen to thrive under a wide range of environmental conditions contributes not only to the confusion in identifying stable and successional stands, but also is reflected in substantial variability in the ability of aspen-dominated sites to produce wildlife habitat, livestock forage, wood, and other needed resources. For example, aspen with a predominant understory of grasses is markedly different wildlife habitat than aspen with an understory dominated by shrubs. Livestock forage production in one range condition class in aspen can vary from 600 to 2,000 pounds of air-dry herbage per acre (672 to 2,242 kilo/ha) because of differences in site potential (Houston 1954). Wood production, measured as annual bole increment, can range from 42 to 194 cubic feet per acre (2.9 to 13.6 m³/ha) because of site and genetic variability (Jones and Trujillo 1975). Theoretically, we should be able to identify meaningful environmental differences among sites and relate these to quantity and quality of resource production.

Attempts to classify aspen sites, as with most other forest and range types, have relied heavily upon using the vegetation as an integrator of the many factors constituting "environment." Such approaches categorize on the basis of species composition in stable, relatively undisturbed plant communities. Such classification efforts for aspen sites have been few and geographically narrow. The difficulty in developing a site potential classification for aspen is compounded by aspen's questionable status as a stable or seral tree on a given site.

Reed (1971) concluded that a single, stable aspen/snowberry type exists in the Wind River Mountains of Wyoming along with seral aspen communities that are succeeded by Douglas-fir, lodgepole pine, and limber pine at the higher elevations. Severson and Thilenius (1976) found both relatively stable and obviously seral aspen stands in the Black Hills and Bear Lodge Mountains of South Dakota and Wyoming which they classified into nine "aspen groups" according to similarity of vegetation and site. Judging from understory composition, Bunin (1975) determined that four stable aspen associations occupy the

west slope of the Park Range in Colorado:

(1) aspen/Gambel oak - serviceberry - meadow rue, (2) aspen/sticky laurel, (3) aspen/meadow rue - aster, and (4) aspen/bracken fern - cow parsnip. She also recognized a seral type that is rapidly succeeded by subalpine fir. And, Pfister (1972), while developing a subalpine forest classification for Utah, found apparently stable aspen communities at lower elevations, but concluded that aspen on upper elevation sites is usually a dominant seral species that will eventually progress to spruce-fir climax.

Such studies as these have helped us to understand the ecological variability of aspen communities throughout the Rocky Mountain area. But this understanding is far from complete. We have hardly begun to provide land managers with the guidelines necessary to reliably relate aspen site variability to the potential of these sites to produce important resources, and to determine how these various sites will respond to management. Development of such guidelines must be in two steps. First, we must develop a realistic classification which partitions the spectrum of variability in site capabilities; then we must quantitatively relate resource production and management to these classification units. Once these steps are taken we will be able to offer precise management prescriptions for specific aspen sites.

LITERATURE CITED

- Barnes, B. V.
1966. The clonal growth habit of American aspen. *Ecology* 47:439-447.
- Barnes, B. V.
1969. Natural variation and delineation of clones of *Populus tremuloides* and *P. grandidentatum* in northern Lower Michigan. *Silvae Genet.* 18:130-142.
- Barnes, B. V.
1975. Phenotypic variation of trembling aspen in Western North America. *For. Sci.* 21:319-328.
- Bunin, J. E.
1975. Aspen forests of the west slope of the Park Range, northcentral Colorado. AIBS meetings, Corvallis, Oreg., Aug. 17-22.
- Houston, W. R.
1954. A condition guide for aspen ranges of Utah, Nevada, southern Idaho, and western Wyoming. U.S. Dep. Agric., For. Serv., Intermt. For. and Range Exp. Stn., Res. Pap. 32, 20 p. Ogden, Utah.
- Jones, J. R., and D. C. Markstrom.
1973. Aspen...an American wood. (*Populus tremuloides* Michx. and *P. grandidentata* Michx.). U.S. Dep. Agric., For. Serv. FS-217, 8 p.

- Jones, J. R., and D. P. Trujillo.
1975. Development of some young aspen stands in Arizona. USDA For. Serv. Res. Pap. RM-151, 11 p. Ft. Collins, Colo.
- Little, E. L.
1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. U.S. Dep. Agric., For. Serv. Misc. Publ. 1146.
- Pfister, R. D.
1972. Vegetation and soils in the subalpine forests of Utah. Ph.D. Diss., Utah State Univ., Logan. 98 p.
- Reed, R.
1971. Aspen forests of the Wind River Mountains, Wyoming. Am. Midl. Nat. 86:327-343.
- Schier, G. A.
1975. Deterioration of aspen clones in the middle Rocky Mountains. USDA For. Serv. Res. Pap. INT-170, 14 p. Ogden, Utah.
- Severson, K. E., and J. F. Thilenius.
1976. Classification of quaking aspen stands in the Black Hills and Bear Lodge Mountains. USDA For. Serv. Res. Pap. RM-166, 24 p. Ft. Collins, Colo.
- Tew, R. K.
1970. Seasonal variation in the nutrient content of aspen foliage. J. Wildl. Manage. 34:475-478.
- Wall, R. F.
1971. Variation in decay in aspen stands as affected by their clonal growth pattern. Can. J. For. Res. 1:141-146.

Physiological And Environmental Factors Controlling Vegetative Regeneration Of Aspen¹

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Abstract.--Formation of suckers on aspen roots is suppressed by auxin transported from the stem. Cutting or injuring the stem decreases the auxin-growth promoter ratio in roots enabling suckering to occur. Carbohydrate reserves supply the energy necessary for bud initiation and shoot outgrowth. Soil temperature is the most important environmental factor controlling suckering.

INTRODUCTION

Aspen (*Populus tremuloides* Michx.) occurs in clones of genetically identical individuals throughout its range (Barnes 1966). The clonal growth habit has resulted because aspen has the ability to regenerate vegetatively by adventitious shoots (suckers, or root sprouts) that originate irregularly on its roots. Under existing climatic conditions in the Rocky Mountains, aspen rarely reproduces from seed (Moss 1938). It has been able to remain a widespread and abundant species only because of its root suckering ability. Fire has played an important role in aspen ecology (Loope and Gruell 1973). Repeated occurrence of fire has enabled clones to increase in size because it resulted in the successive generation of shoots on a continually expanding root system.

Regeneration of aspen will be crucial in any program to manage the species. Because successful regeneration depends on our ability to stimulate sucker production, we should have some knowledge of the physiological and environmental factors controlling sucker formation.

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ORIGIN OF SUCKERS

Suckers arise from the numerous ropelike lateral roots of aspen that occur near the soil surface. They do not originate from pre-existing suppressed buds that arise during normal development of primary tissue in the roots as they do in the balsam and black poplars (Schier and Campbell 1976). Instead, they develop from meristems that appear to arise any time during root growth after the formation of the cork cambium. Meristem development probably occurs in response to a stimulus resulting from disturbances in the clone (Schier 1973b). These meristems may develop into buds and then elongate into shoots, but frequently they do not develop beyond the primordial stage. Later, in response to another stimulus, they may develop further. By peeling off the cork, one can usually see very small mounds, preexisting primordia, protruding from the cork cambium.

APICAL DOMINANCE

There is substantial evidence that the development of suckers on aspen roots is suppressed by auxin transported from growing shoot parts, a phenomenon known as apical dominance (Farmer 1962; Eliasson 1971b, 1971c; Schier 1973d, 1975; Steneker 1974). The transport of auxin to roots must be continuous if inhibiting levels of auxin are to be maintained because auxin is rapidly inactivated (Eliasson 1971c, 1972). Interference with the auxin supply by cutting, burning, girdling, or defoliation decreases auxin concentrations in roots. This enables suckers to be initiated or, if their

growth was suppressed by auxin, to continue to grow.

After logging, the number of suckers on aspen roots is proportional to the number of stems removed; the greatest number of suckers arise after a complete clearcut. Not only does removal of all stems reduce apical control to a minimum, but it also enables this shade-intolerant species to grow in full sunlight where it makes its maximum growth.

Sucker formation does not require anything as drastic as logging or fire. This is evident from the occurrence of thousands of shoot primordia and numerous suckers in various stages of development on the roots of relatively undisturbed aspen clones (Schier 1973b). Subtle environmental changes may weaken apical dominance and trigger sucker formation. During normal seasonal tree growth, there may be periods when auxins are at low levels in roots. This is the case in early spring prior to bud burst when temperatures are high enough for the initiation of suckers. This is generally the only time when potted aspen will produce suckers. However, sucker initiation and growth of established suckers is inhibited after buds have flushed out and apical control has reasserted itself.

Apical dominance also plays an important role in limiting regeneration after an aspen clone is cut. Elongating suckers produce auxins (Eliasson 1971a) and translocation of these into the roots may subsequently increase auxin concentrations to levels that inhibit the initiation and development of additional suckers (Schier 1972).

GROWTH PROMOTERS

Adventitious shoot development in aspen roots is probably initiated by cytokinins, hormones that are synthesized in root tips (Peterson 1975; Skene 1975; Williams 1972). High cytokinin-auxin ratios favor shoot initiation while low ratios inhibit it (Winton 1968; Wolter 1968). Obviously then sucker production can be promoted by decreasing the concentrations of auxin or increasing the concentration of cytokinins. Both of these changes do in fact occur in the roots when a stem is cut because auxins can no longer move into them and cytokinins accumulate where they are synthesized. Less success is probably achieved in stimulating sucker production by girdling a stem than by cutting it because, although downward movement of auxin in the phloem is stopped, translocation of cytokinins into the stem via the xylem is not impeded. Consequently, cytokinins do not accumulate in the roots (Farmer 1962; Skene 1975).

Another growth regulator that appears to promote sucker production is a gibberellic acidlike compound (Schier 1973a; Schier and others 1974). It appears to stimulate shoot elongation after suckers have been initiated. Therefore, any interference with its biosynthesis could affect sucker production even if cytokinin concentrations are high.

CARBOHYDRATE RESERVES

After shoot initiation in aspen is triggered by a change in hormone balances, carbohydrate reserves supply the energy necessary for bud initiation and shoot outgrowth. The regions of the root that give rise to shoot primordia actually may be stimulated by heavy accumulations of starch (Thorpe and Murashige 1970). An elongating sucker remains dependent upon root reserves until it emerges at the soil surface and can carry on photosynthesis (Schier and Zasada 1973). The number of suckers arising on aspen roots generally is not limited by the concentration of stored carbohydrates. However, because sucker growth through the soil is sensitive to slight changes in carbohydrate concentration, the density of regeneration is related to the levels of reserves. Low supplies of carbohydrates might be expected to have a greater impact on deep-rooted clones than on shallow-rooted clones because the former would be required to expend a greater amount of energy to put a sucker at the soil surface.

Although aspen has a high capacity to regenerate itself vegetatively, there are limits to how much abuse it can take. Repeated destruction of new suckers by burning, cutting, herbicide spraying, or heavy grazing can exhaust carbohydrate reserves and cause a drastic reduction in sucker production (Baker 1918; Sampson 1919). Defoliation by insects can also cause root reserves to be depleted and to reduce the amount of aspen regeneration produced when a clone is cut.

ENVIRONMENTAL FACTORS

Soil temperature is one of the most important environmental factors affecting suckering by aspen (Maini and Horton 1966; Williams 1972; Zasada and Schier 1973). High soil temperature in exposed grasslands adjacent to aspen clones is thought to be the primary reason for aspen being able to invade these areas (Barley and Wroe 1974; Maini 1960; Williams 1972). The absence of aspen on cooler sites in interior Alaska is probably due to the inhibiting effect of low soil temperature on sucker regeneration (Zasada and Schier 1973).

A great deal has been made of evidence that increased soil temperatures resulting from insolation can cause suckers to arise from roots of uninjured aspen (Maini and Horton 1966). However, it has also been shown that an increase in soil temperature may not always be sufficient to override the effects of apical dominance, although the temperature increase will promote sucker growth after apical dominance is broken (Steneker 1974).

When suckers arise from roots of undisturbed clones as a result of high soil temperature, as in aspen invasion of grassland, temperature probably has modified the effects of apical dominance by its effect on cytokinin-auxin balances (Williams 1972). High temperature may lower the effective amount of auxin in the roots by causing its degradation. In contrast, cytokinin production by root meristems is increased (Williams 1972). The resulting high cytokinin-auxin ratio stimulates sucker production.

Light and soil moisture may also play an important role in aspen regeneration. Light is not essential for sucker initiation, but it is necessary for good sucker growth (Farmer 1963). Soil moisture may be critical when there is either too much or too little of it (Maini and Horton 1964). Aspen growing under conditions of severe drought or in soil saturated with moisture produces few suckers.

CLONAL VARIATION

Large clonal differences in the relative capacity of clones to produce suckers have been found when suckers are propagated from root cuttings under controlled environmental conditions (Farmer 1962; Maini 1967; Schier 1973d, 1974; Schier and Zasada 1973; Tew 1970; Zufa 1971). The magnitude of the differences among clones varies with the date of collection (Schier 1973d). The number of suckers produced by a clone is determined by the physiological and anatomical characteristics of the roots at the time of collection. Genotype probably has a large influence on these characteristics, but nongenetic factors such as clone history, stem age, clone age from seed, and site could also be major contributors. Sucker production from roots of different clones often responds differently to chemical treatments (Schier 1973a, 1973c) and to temperature treatments (Maini 1967; Zasada and Schier 1973). There is evidence that the natural variation in sucker initiation, development, and response to treatment may be due to clonal differences in concentration of endogenous growth regulators (Barry 1972; Schier 1973d), carbohydrate reserves (Schier and Johnston 1971; Tew 1970),

and to differences in the developmental stages of the shoot primordia (Schier 1973a, 1973c).

The occurrence of clones with an uneven-aged stem structure indicates there are clones in which mortality is quickly replaced by new suckers (Alder 1970). There may be clones in which apical control is so weak or the concentration of growth-promoting factors so high that they sucker vigorously at the least disturbance.

LITERATURE CITED

- Alder, G. M.
1970. Age-profiles of aspen forests in Utah and northern Arizona. M.S. Thesis, Univ. Utah. 31 p.
- Baker, F. S.
1918. Aspen reproduction in relation to management. J. For. 16:389-398.
- Barley, A. W., and R. A. Wroe.
1974. Aspen invasion in a portion of the Alberta parklands. J. Range Manage. 27:263-266.
- Barnes, B. V.
1966. The clonal growth habit of American aspen. Ecology 47:439-447.
- Barry, W. J.
1972. The ecology of *Populus tremuloides*, a monographic approach. Ph.D. Thesis, Univ. Calif., Davis. 730 p.
- Eliasson, L.
1971a. Growth regulators in *Populus tremula* II. Effect of light on inhibitor content in root suckers. Physiol. Plant. 24:205-208.
- Eliasson, L.
1971b. Growth regulators in *Populus tremula* III. Variation of auxin and inhibitor level in relation to root sucker formation. Physiol. Plant. 25:263-267.
- Eliasson, L.
1971c. Growth regulators in *Populus tremula* IV. Apical dominance and suckering in young plants. Physiol. Plant. 25:263-267.
- Eliasson, L.
1972. Translocation of shoot-applied indolylacetic acid in roots of *Populus tremula*. Physiol. Plant. 27:412-416.
- Farmer, R. E., Jr.
1962. Aspen root sucker formation and apical dominance. For. Sci. 8:403-410.
- Farmer, R. E., Jr.
1963. Effect of light intensity on growth of *Populus tremuloides* cuttings under temperature regimes. Ecology 44:409-411.
- Loope, L. L., and G. E. Gruell.
1973. The ecological role of fire in the Jackson Hole area, northwestern Wyoming. Quat. Res. 3:425-443.

- Maini, J. S.
1960. Invasion of grassland by *Populus tremuloides* in the Northern Great Plains. Ph.D. Thesis, Univ. Saskatchewan, Canada. 231 p.
- Maini, J. S.
1967. Variation in the vegetative propagation of *Populus* in natural populations. Bull. Ecol. Soc. Am. 48(2):75-76.
- Maini, J. S., and K. W. Horton.
1964. Influence of temperature and moisture on formation and initial growth of *Populus tremuloides* suckers. Can. Dep. For., For. Res. Br. Rep. 64-0-11, 27 p.
- Maini, J. S., and K. W. Horton.
1966. Vegetative propagation of *Populus* spp. I. Influence of temperature on formation and initial growth of aspen suckers. Can. J. Bot. 44:1183-1189.
- Moss, E. H.
1938. Longevity of seed and establishment of seedlings in species of *Populus*. Bot. Gaz. 99:529-542.
- Peterson, R. L.
1975. The initiation and development of root buds. In The development and function of roots (J. G. Torrey and D. T. Clarkson, eds.), p. 125-161. Acad. Press, New York.
- Sampson, A. W.
1919. Effect of grazing upon aspen reproduction. U.S. Dep. Agric. Bull. 741. 29 p.
- Schier, G. A.
1972. Apical dominance in multishoot cultures from aspen roots. For. Sci. 18:147-149.
- Schier, G. A.
1973a. Effects of gibberellic acid and an inhibitor of gibberellin action on suckering from aspen root cuttings. Can. J. For. Res. 3:39-44.
- Schier, G. A.
1973b. Origin and development of aspen root suckers. Can. J. For. Res. 3:45-53.
- Schier, G. A.
1973c. Effect of abscisic acid on sucker development and callus formation on excised roots of *Populus tremuloides*. Physiol. Plant. 28:143-145.
- Schier, G. A.
1973d. Seasonal variation in sucker production from excised roots of *Populus tremuloides* and the role of endogenous auxin. Can. J. For. Res. 3:459-461.
- Schier, G. A.
1974. Vegetative propagation of aspen: clonal variation in suckering from root cuttings and in rooting of sucker cuttings. Can. J. For. Res. 4:565-567.
- Schier, G. A.
1975. Promotion of sucker development on *Populus tremuloides* root cuttings by an antiauxin. Can. J. For. Res. 5:338-340.
- Schier, G. A., and R. B. Campbell.
1976. Differences among *Populus* species in ability to form adventitious shoots and roots. Can. J. For. Res. 6.
- Schier, G. A., and R. S. Johnston.
1971. Clonal variation in total nonstructural carbohydrates of trembling aspen roots in three Utah areas. Can. J. For. Res. 1:252-255.
- Schier, G. A., R. P. Pharis, and R. C. Durley.
1974. Gibberellinlike substances in aspen (*Populus tremuloides*). In Proc. 3rd N. Am. For. Biol. Workshop, Sept. 9-12, 1974, Colo. State Univ., p. 365-366. (C. P. P. Reid and G. H. Fechner, eds.)
- Schier, G. A., and J. C. Zasada.
1973. Role of carbohydrate reserves in the development of root suckers in *Populus tremuloides*. Can. J. For. Res. 2:243-250.
- Skene, K. G. M.
1975. Cytokinin production by roots as a factor in the control of plant growth. In The development and function of roots (J. G. Torrey and D. T. Clarkson, eds.), p. 365-390. Acad. Press, New York.
- Steneker, G. A.
1974. Factors affecting suckering of trembling aspen. For. Chron. 50:32-34.
- Tew, R. K.
1970. Root carbohydrate reserves in vegetative reproduction of aspen. For. Sci. 16:318-320.
- Thorpe, T. A., and T. Murashige.
1970. Some histochemical changes underlying shoot initiation in tobacco callus cultures. Can. J. Bot. 48:277-285.
- Williams, K. R.
1972. The relationship of soil temperature and cytokinin production in aspen invasion. M.S. Thesis, Univ. New Mexico. 39 p.
- Winton, L. L.
1968. Plantlets from aspen tissue cultures. Science 160:1234-1235.
- Wolter, K. E.
1968. Root and shoot initiation on aspen callus cultures. Nature 219:508-509.
- Zasada, J. C., and G. A. Schier.
1973. Aspen root suckering in Alaska: effect of clone, collection date, and temperature. Northwest Sci. 47:100-104.
- Zufa, L.
1971. A rapid method for vegetative propagation of aspen and their hybrids. For. Chron. 47:36-39.

Diseases Of Western Aspen¹

Thomas E. Hinds^{2/}

Abstract.--Decay fungi cause the greatest impact of all diseases affecting aspen's potential for utilization. Trunk cankers kill trees and cause unknown volume losses. Other diseases presently appear to play only a minor role.

Hardwoods, mainly aspen (*Populus tremuloides* Michx.) currently play a minor role in the timber resources of the Rocky Mountains. By the year 2,000, however, the Forest Service projects that hardwood sawtimber removals could be increased from the 1970 level of 13 million board feet to 232 million board feet providing substantial changes occur in hardwood values, plant capacity, and markets (U.S. Forest Service 1973). If these greatly increased volumes of aspen are to be available and utilized in the future, we will need considerably more information on the impact of diseases on aspen management.

Although many diseases attack aspen, relatively few cause loss in living trees. Of these, decay fungi cause the greatest loss in merchantable volume and are responsible for shortening the rotation age. Cankers not only kill the bark and distort the merchantable portions of the trunk, but also cause extensive mortality. The root pathogens not only cause extensive butt rot, but more importantly, predispose trees to windthrow. While leaf diseases may cause some growth loss, they seldom kill trees, and are not usually considered important.

The relative importance of the diseases of aspen found in the West differ from those found in the eastern United States and Canada. This discussion summarizes our present knowledge on some of the important disease problems concerned with management and utilization of aspen in the southern Rocky Mountains.

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DECAY

Losses Due to Decay

Baker (1925) was the first to stress the role of decays in aspen management in the West. He presented criterion for site quality, and gave gross cull estimates based on his studies in central Utah. Baker recommended a pathological rotation age of about 110 years on what he had defined as sites 1 and 2, the better aspen sites, to minimize decay losses.

The only quantitative study of aspen decay in the West was by Davidson et al. (1959) in Colorado. In the Colorado study, 53 percent of 976 trees sampled contained decay, which averaged 8.4 percent of the total cubic foot volume. Although there was little relationship between decay and site class for younger stands, the differences were marked in older stands. In 100-year-old stands, cubic foot decay averaged 4 percent on site 1, 8 percent on site 2, and 13 percent on site 3. The incidence of decay was considerably lower than that reported by Meinecke (1929) for aspen in one locality in northern Utah.

The merchantability of aspen on a board-foot basis was recently analyzed^{3/} by grouping the Colorado data (Davidson et al. 1959) for individual trees (minimum tree d.b.h. 8.0 inches) by 10-year age classes. Cull due to decay plotted as a function of these age classes for Baker's sites 1 and 2 (Baker 1925) showed an essentially linear relationship for the range of the data--40 to 170 years:

^{3/} Hinds, T. E., and E. M. Wengert. Growth and decay losses in Colorado aspen. Manuscript in preparation, Rocky Mountain Forest and Range Experiment Station.

Tree Age (years)	Percent board foot cull due to decay	
	Site 1 ^{4/}	Site 2 ^{5/}
60	6	7
80	13	16
100	21	25
120	28	34
140	36	44
160	44	53

^{4/} Site 1 percent cull = $-17 + .38$ tree age,
 $r = .93$

^{5/} Site 2 percent cull = $-21 + .46$ tree age,
 $r = .96$

The amount of cull for trees on site 3 averaged 65 percent between 70 and 150 years, but the variation was too large to obtain meaningful relationships.

It appears that sawtimber harvest of aspen on sites 1 and 2 should be optimum when stands are between 90 and 120 years of age. Defect should range between 17 and 34 percent. On poorer sites only marginal utilization of the stands can be expected. In essence, the Colorado and Utah studies dispel the idea that western aspen should be managed on a short rotation period (from about 30 years on poor sites to 50 or 60 years on good sites) similar to the Lake States aspen (Brinkman and Roe 1975).

Types of Decay

Trunk rot was responsible for two thirds of the aspen board foot cull in Colorado^{3/}. Decay by Phellinus tremulae (=Fomes ignarius), commonly recognized as the principal cause of trunk rot cull in aspen, was found in 15 percent of the trees and was responsible for a third of the total cull. Many trees with extensive trunk rot have conspicuous conks (fruiting bodies) on the trunk. The estimated board foot cull for an individual tree with 1 to 3 conks at any height, or any number of conks 0 to 16 feet on the bole, is $59 + 3$ percent. A tree with conks not in these two classes should be considered a total cull (Hinds 1963).

The second most important trunk rot fungus is Peniophora polygonia. Although its incidence of infection is greater than P. tremulae, it causes much less loss. The fungus does not fruit readily on infected trees, consequently there are no external indications that decay is present. Actual cull attributed to this rot is probably less than that scaled because the incipient stage does not fall out when sawn lengthwise, and is usually considered stained wood.

The remaining trunk rot fungi, with the exception of Libertella sp., cause only minor amounts of decay.

More species of fungi are associated with butt rots than trunk rots. Although butt rots were responsible for only a third of the decay volume in Colorado (Davidson et al. 1959), their true importance is unknown. If the volume losses attributable to windthrow due to root diseases were included (Ross 1976a), their impact would be much greater.

Collybia velutipes causes the greatest amount of butt cull (Davidson et al. 1959). The brown mottle rot often extends above 16 feet in older trees. Ganoderma applanatum (=Fomes applanatus) may be as important as C. velutipes because it not only causes a brown mottle butt rot, but also decays the large roots (Ross 1976b) and is a major cause of windthrow (Landis and Evans 1974). Fruiting bodies of the fungus found at the base of a tree indicate butt cull. They are found in almost all aspen stands. With the exception of Pholiota squarrosa, the other butt rot fungi apparently cause only minor amounts of decay (Ross 1976b).

CANKERS

Trunk cankers are the most obvious disease problem on aspen (Hinds and Krebill 1975). Many fungi infect trunk wounds and kill the living bark tissue, causing annual and perennial cankers. The perennial cankers are the most important for they gradually enlarge until they girdle and kill the tree. Although the slow-growing persistent infections may never girdle, the infected trunk becomes so deformed that it is useless for commercial purposes.

The only study to determine the distribution and abundance of the different aspen cankers in the Rocky Mountains was made in Colorado in 1960. Based on 31 plots (129 sub-plots) in 5 National Forests, canker incidence on live trees was: Cytospora, 4.3 percent; Cenangium, 2.4 percent;

Ceratocystis 4.1 percent; and Hypoxylon, 0.2 percent (Hinds 1964). Nine percent of the trees were dead but still standing. The proportion of the dead trees with cankers was: Cytospora, 54 percent; Cenangium, 51 percent; Ceratocystis, 9 percent; and Hypoxylon, 2 percent. The cankers, with the exception of Hypoxylon, were fairly well distributed throughout the Forests. Several types of trunk wounds were also noted.

Trunk wounds are the infection site for most aspen canker diseases. The relationship of trunk wounds to canker-caused mortality was brought out by Krebill (1972) in his study of aspen mortality on the Gros Ventre elk winter range. Aspen mortality in campgrounds is likewise related to camper-caused trunk wounds. Over 50 percent of the trunk wounds in an extensive campground study were infected, and 98 percent of the tree mortality was attributed to the various canker organisms (Hinds 1976).

The important canker diseases are discussed below.

Cenangium Canker

Sooty-bark canker, caused by Cenangium singulare, is one of the major causes of aspen mortality in the West. The fungus was associated with the canker in 1956 (Davidson and Cash 1956), and has since been found from British Columbia southward through the Rocky Mountains into New Mexico and Arizona (Andrews and Eslyn 1960). The fungus infects trunk wounds, penetrates the inner bark and cambium, and spreads rapidly. Cankers can extend to 40 inches in length in 1 year, and reach 12 feet long by 29 inches in width in 4 years (Hinds 1962). Trees of all sizes are killed, usually within 3-10 years. Sapwood stain is common behind the canker, but decay does not usually develop because the dead bark dries out fairly rapidly. A cankered live tree should not be considered a cull, even though the canker is extensive.

Ceratocystis Canker

Black canker is the common name given to this canker (Boyce 1948) described over half a century ago (Long 1918). The canker is characterized as "target-shaped" when young, but is ragged in appearance due to massive callus folds and flaring dead bark which is black when the infection is many years old. While it is probably the most common canker found in western aspen stands, tree mortality is not great (Hinds 1964). Ceratocystis fimbriata can attack through the epidermis of leaf blades, petioles, and young stems (Zalasky 1965) but trunk wounds are considered to be the primary courts of infection (Hinds 1972a)

and insects the primary vectors (Hinds 1972b). The major impact of Ceratocystis canker is trunk deformity; it is not usually associated with decay.

Hypoxylon Canker

Hypoxylon canker of aspen, caused by Hypoxylon mammatum, causes serious mortality only in localized areas in the southern Rockies. (Hinds 1964, Hinds and Jones 1965). It was first observed in the western United States in 1955 (Davidson and Hinds 1956) and has since been observed more frequently on individual trees in the more open aspen stands. While it is estimated that Hypoxylon canker kills 1-2 percent of the aspen volume annually in the Lake States region (Anderson 1964), its overall importance in western commercial stands is unknown.

It does not normally cause trunk rot or tree breakage in the West, where cankers may be 20+ years old before they girdle large aspens. Because the dead cankered tissue and underlying sapwood dry out fairly rapidly, a cankered tree should not be considered a cull.

Cytospora Canker

Cytospora chrysosperma causes bark necrosis, lesions, and cankers on trunks, large limbs, small branches, and twigs. The fungus is a normal inhabitant of the aspen bark microflora, and readily enters and parasitizes bark that has been injured or weakened (Christensen 1940). The disease is most serious on young suppressed trees, and trees that have been stressed by environmental or biological agents (Long 1918). Although Cytospora is often found associated with other cankers, it is not considered a primary parasite on healthy trees.

Cryptosphaeria Canker

Cryptosphaeria canker is a relative newcomer to the list of aspen cankers. Although the fungus Cryptosphaeria populina was collected on aspen in Colorado in 1897 by E. Bethel, it has only recently been associated with cankers. The elongated trunk cankers, common in many western aspen stands (Hinds 1976, Krebill 1972) are 3-20+ feet long but only 2-6 inches wide. They may spiral around the tree like a snake. Extensive trunk rot is associated with the canker, and trees with large cankers are frequently broken off by the wind. Based on canker symptoms alone, this canker probably has been misidentified as Cytospora canker in the past. The importance of this canker in causing tree mortality and its associated decay remains to be determined.

STAIN AND WETWOOD

Stain (discoloration) is very common in aspen. The discolorations include hues of black, brown, red, yellow, and green. Although decay and canker fungi are frequently associated with various stains, many other micro-organisms are involved, some in a successional manner leading to decay (Shigo 1967). Stain normally affects lumber quality rather than quantity; cull deduction is not usually made when the stain is firm and light in color. (U.S. Forest Service 1964).

The amount of stain in western aspen is unknown, but it may be extensive in trees of saw log size. In an Ontario aspen decay study, the proportion of two types of stain increased from about 13 percent of the merchantable volume in stands 41 to 60 Years old to over 24 percent in stands over 120 years old (Basham 1958). The effect of stain on lumber degrade loss needs study.

"Wetwood," a water-soaked condition of wood in living trees, is likewise common in both sapwood and heartwood of aspen (Knutson 1973). Wetwood areas are usually slightly discolored on a cross section of the bole. While wetwood has been associated with wood borers, wounds, and frost cracks in western aspen (Davidson et al. 1959), it also occurs without obvious associations. High populations of bacteria and yeast are found in wetwood, but their role in wetwood formation is uncertain (Knutson 1973).

Lumber drying is perhaps the biggest problem associated with wetwood. The discoloration largely disappears upon drying, but the wood may collapse at the zone between heartwood and sapwood, split and crack, and not meet thickness requirements. Air-seasoning boards containing wetwood prior to kiln-drying reduces collapse losses at mills (Clausen et al. 1949). There are no data on losses attributed to wetwood during the milling process.

MISCELLANEOUS DISEASES

Leaf diseases may have local significance, but their damage is usually confined to reduced growth of severely affected trees. Small trees suffer the most damage, and are sometimes killed by repeated infections. Clonal susceptibility to individual foliage diseases is common, but under optimum conditions whole stands become infected.

The black leaf spot caused by Marssonina populi is probably the most common leaf disease on western aspen. Damage is sometimes

widespread covering several hundreds of acres. It has been reported to cause twig and branch mortality, and dieback in the Intermountain Region (Mielke 1957). Annual infection usually repeats only in the lower crown, and the dieback report has not been substantiated.

Ink spot, caused by Ciborinia whetzellii (Baranyay and Hiratsuka 1967) periodically causes considerable early defoliation, particularly on small trees and the lower portion of larger trees.

The "shepherd's crook" disease, manifested by a blackened reflexed shoot with dead leaves, is caused by Venturia tremula (Dance 1959). While larger trees may be relatively unaffected, the current growth of suckers may be severely attacked, resulting in deformed stems. The disease can be severe on regeneration in clear cut areas. Leaf rusts occur sporadically throughout the region, with Melampsora medusa being the most common (Ziller 1965). The alternate hosts needed for the rust's life cycle include several conifers commonly associated with aspen. The primary effect of Melampsora, like Marssonina, is premature leaf drop in the fall. Damage in aspen stands is not considered serious.

Fungi are associated with two types of rough-bark common on the otherwise smooth aspen bark. The fungus Diplodia (Macrophoma) tumefaciens causes woody galls on branches and twigs and gray to black rough bark outgrowths which tend to encircle the bole (Zalasky 1964). Bark infected by Rhytidiella baranyayi tends to be more corky and lighter in appearance, with smaller affected areas frequently angular shaped on larger trees (Funk and Zalasky 1975). Both fungi may persist in the bark many years, but apparently do little harm to the tree.

FUTURE OUTLOOK

Because most aspen stands in the southern Rockies originated following fires within the last 150 years, we cannot expect to see much further expansion of the type. Today it is not unusual to find two age-class stands. Three-age and uneven-aged stands are also to be found. The differences between age classes must be recognized in assessing merchantability of aspen stands.

It is estimated that 29 percent of the commercial aspen forests in the National Forests of the southern Rockies contain sawtimber: trees over 11.0 inches d.b.h. (Green and Setzer 1974). In many of these older stands, decay cull can be expected to run over 20 percent.

Many of these stands are deteriorating and the sites are reverting to conifers. Unless the rate of harvest increases in these older stands, there is the danger of losing untold acres of the aspen type. These older stands on the better sites should be harvested soon so that the site can be retained by aspen and once again made productive.

Half of the commercial areas contain poletimber stands: trees 5.0-10.9 inches d.b.h (Green and Setzer 1974). It is this important size class which should be harvested in the next 2 or 3 decades while the net growth increment is still high. Tree age presently ranges up to 80 years on the better sites.

Although decay will continue to have a long-term impact on the harvest of aspen, the role of canker mortality should not be overlooked. Future studies may show that losses to leaf and root diseases are important under more intensive management.

LITERATURE CITED

- Anderson, R. L. 1964. Hypoxylon canker impact on aspen. *Phytopathology* 54:253-257.
- Andrews, S. R., and W. E. Eslyn. 1960. Sooty-bark canker of aspen in New Mexico. *Plant Dis. Rep.* 44:373.
- Baker, F. S. 1925. Aspen in the central Rocky Mountain region. U.S. Dep. Agric. *Bull.* 1291, 46 p.
- Baranyay, J. A., and Y. Hiratsuka. 1967. Identification and distribution of *Ciborinia whetzeli* (Seaver) Seaver in western Canada. *Can. J. Bot.* 45:189-191.
- Basham, J. T. 1958. Decay of trembling aspen. *Can. J. Bot.* 36:491-505.
- Boyce, J. S. 1948. *Forest pathology*. McGraw-Hill Book Co., New York, 550 p.
- Brinkman, K. A., and E. I. Roe. 1975. Quaking aspen: silvics and management in the Lake States. U. S. Dep. Agric. *Handb.* 486, 52 p.
- Christensen, C. M. 1940. Studies on the Biology of *Valsa sordida* and *Cytospora chrysosperma*. *Phytopathology* 30:459-475.
- Clausen, V. H., L. H. Ress, and F. H. Kaufert. 1949. Development of collapse in aspen lumber. *For. Prod. Res. Soc. Proc.* 3:460-468.
- Dance, B. W. 1959. A cultural connection between *Venturia tremulae* Aderh. and its imperfect stage in Ontario. *Can. J. Bot.* 37:1139-1140.
- Davidson, R. W., and E. K. Cash. 1956. A *Cenangium* associated with sooty-bark canker of aspen. *Phytopathology* 46: 34-46.
- Davidson, R. W., and T. E. Hinds. 1956. Hypoxylon canker of aspen in Colorado. *Plant Dis. Rep.* 40:157-158.
- Davidson, R. W., T. E. Hinds, and F. G. Hawksworth. 1959. Decay of aspen in Colorado. U. S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., *Stn. Pap.* 45, 14 p.
- Funk A., and H. Zalasky. 1975. *Rhytidiella baranyayi* n. sp. associated with cork-bark of aspen. *Can. J. Bot.* 53:752-755.
- Green, A. W., and T. S. Setzer. 1974. The Rocky Mountain timber situation, 1970. USDA For. Serv. Resour. *Bull.* INT-10. 78 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Hinds, T. E. 1962. Inoculations with the sooty-bark canker fungus on aspen. *Plant Dis. Rep.* 46:57-58.
- Hinds, T. E. 1963. Extent of decay associated with *Fomes igniarius* sporophores in Colorado aspen. U.S. For. Serv. Res. Note RM-4, 4 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Hinds, T. E. 1964. Distribution of aspen cankers in Colorado. *Plant Dis. Rep.* 48:610-614.
- Hinds, T. E. 1972a. *Ceratocystis* canker of aspen. *Phytopathology* 62:213-220.
- Hinds, T. E. 1972b. Insect transmission of *Ceratocystis* species associated with aspen cankers. *Phytopathology* 62:221-225.
- Hinds, T. E. 1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. *Pap.* RM-164, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Hinds, T. E., and J. R. Jones. 1965. Hypoxylon canker of aspen in Arizona. *Plant Dis. Rep.* 49:480.
- Hinds, T. E., and R. G. Krebill. 1975. Wounds and canker diseases on western aspen. USDA For. Serv., For. Pest Leaflet 152, 9 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

- Knutson, D. M. 1973. The bacteria in sapwood, wetwood, and heartwood of trembling aspen (Populus tremuloides). Can. J. Bot. 51:498-500.
- Krebill, R. G. 1972. Mortality of aspen on the Gros Ventre elk winter range. USDA For. Serv. Res. Pap. INT-129, 16 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Landis, T. C., and A. K. Evans. 1974. A relationship between Fomes applanatus and aspen windthrow. Plant Dis. Rep. 58:110-113.
- Long, W. H. 1918. An undescribed canker of poplar and willows caused by Cytospora chrysosperma. J. Agric. Res. 13:331-343.
- Meinecke, E. P. 1929. Quaking aspen: a study in applied forest pathology. U.S. Dep. Agric. Tech. Bull. 155, 34 p.
- Mielke, J. L. 1957. Aspen leaf blight in the Intermountain Region. U.S. Dep. Agric., For. Serv., Intermt. For. and Range Exp. Stn., Res. Note 42, 5 p.
- Ross, W. D. 1976a. Fungi associated with root diseases of aspen in Wyoming. Can. J. Bot. 54:734-744.
- Ross, W. D. 1976b. Relation of aspen root size to infection by Ganoderma applanatum. Can. J. Bot. 54:745-751.
- Shigo, A. L. 1967. Successions of organisms in discoloration and decay of wood. Int. Rev. For. Res. 2:237-299.
- Forest Service. 1973. The outlook for timber in the United States. U.S. Dep. Agric., For. Resour. Rep. 20. 367 p. Wash., D.C.
- Forest Service. 1964. National Forest log scaling handbook. U.S. Dep. Agric. For. Serv. FSH 2443.71. 193 p., Wash., D.C.
- Zalasky, H. 1964. Nomenclature and description of Diplodia tumefaciens (Shear) Zalesky (= Macrophoma tumefaciens Shear and Hubert). Can. J. Bot. 42:1049-1055.
- Zalasky, H. 1965. Morphology of Ceratocystis fimbriata in aspen. Can. J. Bot. 43:625-626.
- Ziller, W. G. 1965. Studies of Western tree rusts VI. The aecial host ranges of Melampsora albertensis, M. medusae, and M. occidentalis. Can. J. Bot. 43:217-230.

Aspen Harvesting And Reproduction¹

John R. Jones^{2/}

Abstract.--When aspen stands are clearcut, regeneration by root suckers is usually prompt and abundant and grows rapidly. Partial cutting results in an inferior replacement stand. Dense young stands thin themselves. Artificial thinning is not advised. Many old stands are too decayed to harvest, and constitute a major management problem. Additional overmature stands, uncut, continually move into the cull category.

INTRODUCTION

A major purpose in harvesting aspen is to perpetuate aspen forest for all of its resource values--esthetics, wildlife habitat, and watershed cover as well as for lumber and fiber. Timely and proper harvest is especially important with aspen because aspen does not store well on the stump. Old aspen trees usually become rotten, and old stands may be succeeded by conifers or possibly by sagebrush and bunchgrass (DeByle 1975). Besides harvesting, the other major means of rejuvenating aspen stands, a severe fire, is hard to get when you want it (Fechner and Barrows 1976). And severe fire may be undesirable in many cases, or even unacceptable, for assorted reasons.

To get healthy fully stocked aspen replacement stands that are esthetically pleasing and will produce good crops of timber requires more than just harvesting however. It requires correct harvesting.

Kim Harper and I are writing a book on the ecology and management of western aspen, with help from Norb DeByle and Gene Wengert. It is a detailed reference work. Here I will simply hit some key features of harvesting and reproduction.

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SITES

Many aspen stands grow on sites that don't have the potential to produce economic crops of lumber or fiber. They may however produce usable crops of browse, autumn color, or fuelwood. The culture of aspen may be desirable on such sites, and the most economical means may be deficit sales for fuelwood or chips.

But in this talk I will consider only sites that can produce sawtimber at reasonable rotation ages. Decay makes long rotations highly questionable on most sites. A site that takes, say, 130 years to produce codominant trees 10 to 12 inches in diameter is seldom a commercial site for aspen because of decay. It may be someday, but not today or tomorrow.

Aspen stands on some sites may be heavily invaded by Engelmann spruce, subalpine fir, white fir or Douglas-fir in various combinations, or occasionally by other conifers. Where such a site produces good crops of aspen it may still be preferable to favor the coniferous understory in management and grow a coniferous forest on the site. But even very careful harvesting of the aspen will cause some gaps in the coniferous understory, and aspen root suckers will then result in at least a light mixture of aspen, occupying gaps. That is desirable. Should wildfire, wind, or beetles ravage the conifers later, the scattered aspen would reforest the site promptly with root suckers, once again to provide a favorable microsite for reestablishment of the conifers.

From here on I will talk about the harvesting of productive sites where aspen is to be retained as the cover type.

HARVESTING

HOW HEAVILY TO CUT

In general, researchers and experienced aspen managers in the Lake States, Canada, and the West favor or even insist on clearcutting aspen, to get regeneration stands with a minimum of gaps and the best possible growth (Weigle and Frothingham 1911; Sampson 1919; Baker 1925; Zehngraff 1947, 1949; Curtis 1948; Sandberg 1951; Perala 1972; Brinkman and Roe 1975).

On the other hand, Steneker (1972) stated that in central Canada, leaving culls was not detrimental to suckering if the culls "do not form a closed canopy." Larson (1959) reported that cutting only 45 percent of an Arizona stand provided full restocking, with sucker height at age 7 not much less than on an adjacent clearcut. That paper may have influenced thinking on how heavily aspen must be cut to get a good replacement stand in the West. However, the much more complete data in the office report do not agree with the publication. On the study block, in contrast to the operation as a whole, partial cutting had reduced stocking much more than 45 percent--actually to less than 15 ft² of basal area per acre. That approaches a clearcutting.

A nearby 50-year-old stand had been high-graded, leaving a basal area of 69 ft² per acre. Fifteen years later, whatever suckers may have resulted had disappeared (Martin 1965).

Aspen harvests on the San Juan National Forest have been partial cuts, often heavy. Culls and trees too small for the market were left. They were more or less numerous. Suckering often was heavy, but somewhat irregular. Sucker growth was even more irregular. Growth has been good in the open, for these are good sites. Where residual canopy trees were more numerous, the suckers did not grow well. The result is a stand of irregular structure and growth, distinctly inferior to the parent stands.

These young stands would be better, in many cases much better, if the unmerchantable older trees had been felled at the time of logging or right afterward. The felling of unmerchantable trees on new aspen cutovers has been a standard practice on National Forests in the Lake States for many years (Brinkman and Roe 1975).

As a rule of thumb, I suggest that if the residual unmerchantable stand will be as much as 10 ft² of basal area per acre, unmerchantable

trees should be felled. That is a judgement figure.

Aspen advance regeneration is likely to be of inferior quality. If there are patches of it in the stand, they usually should be destroyed. They are good places to fell tops or rout skidders through.

Curtis (1948) cited a suggestion from Utah that about 60 percent of the stand volume be taken in a first cut, accelerating growth in the smaller canopy trees, which would be cut about 10 years later when they had grown larger. Something much like that was done in a Minnesota experiment. Variable suckering resulted from the partial cuttings. Sucker growth was inferior to that on an adjacent clearcut. The residual stands were completely removed 6 years later. The suckers resulting from the final cut were suppressed by the poor suckers from the first cut. The replacement stands were the inferior result of the first cut--poor stands on good sites.

A poor stand on a good site is not what we want. We have too many of those already.

SKIDDING

Heavy equipment running all over the place can be bad news. This is particularly obvious on sites where a stand of mixed conifers has been heavily cut and the slash bulldozed. On such areas, even where aspens were numerous in the overstory, suckering is often very patchy--largely absent where traffic was heaviest. There may be very few or no suckers on and around the sites of slash piles or log landings.

Almost all aspen suckers arise from roots within a few inches of the surface (Sandberg 1951). Jammer skidding and heavy tractor traffic tear up a lot of these shallow roots, and poor restocking can result. Skidders can move around freely to hook up with no harm. But once they have their load they should use established trails repeatedly instead of bee-lining for the landing.

This may sound peculiar to some of you who are aware that diskings was at one time recommended in the Lake States to stimulate suckering (Zehngraff 1946, 1949; Zillgitt 1951). Stimulation of suckering probably resulted from destruction of competing hazel and mountain maple brush to a large extent. Disking also disrupted the apical dominance of remaining unmerchantable trees.

This too should have helped suckering (Zehngraff 1949). Development of the regenera-

tion stands after disking was not good however, and disking is no longer recommended (Perala 1972, Brinkman and Roe 1975).

THE SUCKER STAND

Aspen sucker stands on a clearcut or burn can look terribly overstocked. Actually, 20 or 30 thousand suckers per acre does not seem excessive at all, and there is no evidence that even 100,000 are too many to start with. Studies in Utah and Arizona (Sampson 1919, Baker 1925, Smith et al. 1972, Jones 1975, Jones and Trujillo 1975) as well as in Michigan (Graham et al. 1963) and Canada (Pollard 1971) indicate that early natural thinning is heavy and effective. The least vigorous suckers die during the first year or two. This first thinning reduces sucker clumps to one or two dominant sprouts. Many other suckers are overtopped soon afterward and die within a few years. Four years after clearcutting on some Arizona plots, about 40 percent of the recognizable suckers had died, leaving about 15,700 survivors per acre. About 40 percent of the survivors were overtopped. As stands continue to develop there is a constant dropping out of canopy trees into the overtopped class, and periodic die-offs of overtopped trees.

Dominants in the sucker stand commonly measure 5-10 feet tall 4 years after clearcutting in the West (Smith et al. 1972; Jones 1967a, 1975; Jones and Trujillo 1975).

During the first few years there are continuous losses of suckers to browsing by deer and elk. In heavily stocked sucker stands these losses are of little consequence, even if they number a few thousand per acre (Smith et al. 1972, Jones 1975). Heavy stands provide an adequate buffer unless sheep use the area the first 3 or 4 years or unless the concentrations of elk or deer are exceptionally high (Sampson 1919, Westell 1956, Packard 1942, Larson 1959, Jones 1967b, Smith et al. 1972). Poorly stocked stands are much more susceptible to being browsed out.

Everything considered, the dense regeneration which normally follows the clearcutting of aspen stands is a plus in providing abundant high-quality forage for big game while providing enough survivors for well-stocked sapling stands. And self thinning avoids stagnation.

None the less, the high density of many aspen regeneration stands has repeatedly spurred interest in thinning. A considerable literature has grown up on precommercial thinning of young aspen (Baker 1925; Zehngraft 1947, 1949; Zasada 1952; Strothmann and Heinzelman 1957; Steneker and Jarvis 1966; Sorensen 1968;

Schlaegel 1972; Bella 1975). Precommercial thinning has only a minor effect on the diameter growth of dominants, although the growth improvement in codominants is more substantial. Thinning reduces stand volume growth.

Thinned plots in young aspen appear to be growing much better than adjacent unthinned plots, but the appearance is deceiving. The many scrawny overtopped trees on the unthinned plots have a strong visual impact. On the thinned plots one sees only dominants and strong codominants.

Meanwhile thinning increases susceptibility to the poplar borer (Ewan 1960). Sunscald has not been reported from thinned sapling stands. But hypoxylon canker, and in the West other cankers, increase after thinning, because of bark wounding and perhaps in part to increased insect activities (Gruenhagen 1945, Graham and Harrison 1954, Anderson and Anderson 1968, Bagga and Smalley 1969, Hinds 1976).

Having said all this, I will mention a stand in which thinning at age 5 or 6 is said to have improved volume growth markedly. No particular disease problem resulted. This stand is on the Mancos District of the San Juan National Forest. I hope to measure some plots there shortly.

Compared to precommercial thinning, commercial thinning has the added attraction of partly or entirely paying for itself, and a number of studies have been reported (Bickerstaff 1946, Pike 1953, Heinzelman 1954, Martin 1965, Steneker and Jarvis 1966, Schlaegel and Ringold 1971, Hubbard 1972). There have been modest growth increases on the remaining trees. In some cases subsequent veneer production was increased. Trees which would otherwise have been lost were salvaged. Overexposed trunks are subject to sunscald however, and canker infections may increase substantially.

I do not recommend commercial or precommercial thinning. There may be situations where thinning is desirable--where it improves stand values and is safe. If so, we need to define situations and methods before we launch any thinning programs

DECADENT STANDS

Many good aspen sites bear stands that are growing poorly and have little commercial volume. This is because of old age, fire scars, irregular stand structures or other reasons. These stands may be almost completely cull, and in some locales they are the rule.

Yet the sites they occupy have the potential to grow 100-200 cubic feet of usable bole wood per acre per year (Green and Setzer 1974, Jones and Trujillo 1975). Occupied by cull stands they produce no usable wood at all.

These are the real problem stands.

Fortunately, if stocking is not extremely poor, old cull stands have the potential to produce heavy stands of healthy suckers if clearcut or burned (Weigle and Frothingham 1911, Baker 1925, Maini 1968, and personal observation). Uncut, they get worse year by year, and additional stands join their ranks. At the present rate of cutting, cull stands will be a much greater problem in the year 2010 than they are now.

Replacing existing cull stands with young vigorous stands is not a matter of marketing and utilization. It is a matter of purpose, will, and financing. However, harvesting other mature and overmature stands on good sites--stands still merchantable--can reduce recruitment to the cull class. And that is a matter of marketing and utilization.

CONCLUSION

Aspen on good sites is a highly productive forest type, and silviculturally our simplest. It is currently suffering from neglect or poor handling because markets do not support satisfactory silviculture. We have the know-how right now, however, to manage aspen well on good sites when markets allow.

LITERATURE CITED

- Anderson, Gerald W., and Ralph L. Anderson.
1968. Relationship between density of quaking aspen and incidence of hypoxylon canker. *For. Sci.* 14:107-112.
- Bagga, Davinderjit, and Eugene B. Smalley.
1969. Factors affecting canker development on *Populus tremuloides* artificially inoculated with *Hypoxylon pruinautum*. *Can. J. Bot.* 47:907-914.
- Baker, Frederick S.
1925. Aspen in the central Rocky Mountain region. U.S. Dep. Agric., Bull. 1291, 47 p.
- Bella, I. E.
1975. Growth-density relations in young aspen sucker stands. North. For. Res. Cent., Inform. Rep. NOR-X-124, 12 p. Edmonton, Alta., Can.
- Bickerstaff, A.
1946. The effect of thinning upon the growth and yield of aspen stands. *Dom. For. Serv., Silv. Res. Note* 80, 30 p.
- Brinkman, Kenneth A., and Eugene I. Roe.
1975. Quaking aspen: silvics and management in the Lake States. U.S. Dep. Agric., For. Serv., Agric. Handb. 486, 52 p.
- Curtis, James D.
1948. Aspen: the utility timber crop of Utah. *Timberman* 49:56-57, 116.
- DeByle, Norbert V.
1975. The aspen ecosystem in the mountainous west--a quest for acceptable management. Paper read at the 26th Annual AIBS Meeting, Corvallis, Ore., Aug. 18, 1975.
- Ewan, Herbert G.
1960. The poplar borer in relation to aspen stocking. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Tech. Note 580, 2 p. St. Paul, Minn.
- Fechner, Gilbert H., and Jack S. Barrows.
1976. Aspen stands as wildfire fuel breaks. *Eisenhower Consortium Bull.* 4, 26 p.
- Graham, Samuel A., and Robert P. Harrison.
1954. Insect attacks and hypoxylon infections in aspen. *J. For.* 52:741-743.
- Graham, Samuel A., Robert P. Harrison, Jr., and Casey E. Westell, Jr.
1963. Aspens: phoenix trees of the Great Lakes Region. 272 p. Univ. Mich. Press, Ann Arbor.
- Green, Alan W., and Theodore S. Setzer.
1974. The Rocky Mountain timber situation, 1970. USDA For. Serv., Resour. Bull. INT-10, 78 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.
- Gruenhagen, R. H.
1945. Hypoxylon pruinautum and its pathogenesis on poplar. *Phytopathology* 35:72-89.
- Heinselman, Miron L.
1954. Thinning from above reduces total yields in medium site aspen. U.S. Dep. Agric. For. Serv., Lake States For. Exp. Stn., Tech. Note 411, 1 p. St. Paul, Minn.
- Hinds, Thomas E.
1976. Aspen mortality in Rocky Mountain campgrounds. USDA For. Serv. Res. Pap. RM-164, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Hubbard, John W.
1972. Effects of thinning on growth and yield. Pages 126-130 in *Aspen: symposium proceedings*. USDA For. Serv., Gen. Tech. Rep. NC-1. North Cent. For. Exp. Stn., St. Paul, Minn.
- Jones, John R.
1967a. Aspen site index in the Rocky Mountains. *J. For.* 65:820-821.
- Jones, John R.
1967b. Regeneration of mixed conifer clear-cuttings on the Apache National Forest, Arizona. U.S. Forest Service, Res. Note RM-79, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

- Jones, John R.
1975. Regeneration on an aspen clearcut in Arizona. USDA For. Serv., Res. Note RM-285, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Jones, John R., and David P. Trujillo.
1975. Development of some young aspen stands in Arizona. USDA For. Serv., Res. Pap. RM-151, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Larson, Merlyn M.
1959. Regenerating aspen by suckering in the Southwest. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note 39, 2 p. Fort Collins, Colo.
- Maini, J. S.
1968. Silvics and ecology of *Populus* in Canada. Pages 20-69 in J. S. Maini and J. H. Cayford, Growth and utilization of poplars in Canada. Can. For. Branch, Dep. Publ. 1205.
- Martin, E. C.
1965. Growth and change in structure of an aspen stand after a harvest cutting. U.S. For. Serv., Res. Note RM-45, 2 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Packard, Fred Mallery.
1942. Wildlife and aspen in Rocky Mountain National Park, Colorado. Ecology 23:478-482.
- Perala, D. A.
1972. Regeneration: biotic and silvicultural factors. Pages 97-101 in Aspen: symposium proceedings. USDA For. Serv., Gen. Tech. Rep. NC-1. North Cent. For. Exp. Stn., St. Paul, Minn.
- Pike, R. T.
1953. Thinning aspen, Duck Mountain Forest Reserve Manitoba. Can. For. Branch, Silv. Leaflet 89, 3 p.
- Pollard, D. F. W.
1971. Mortality and annual changes in distribution of above-ground biomass in an aspen sucker stand. Can. J. For. Res. 1: 262-266.
- Sampson, Arthur W.
1919. Effect of grazing upon aspen reproduction. U.S. Dep. Agric., Bull. 741, 29 p.
- Sandberg, Dixon.
1951. The regeneration of quaking aspen by root suckering. 172 p. Grad. rep., Sch. of For., Univ. Minn.
- Schlaegel, Bryce E.
1972. Growth and yield of managed stands. Pages 109-112 in Aspen: symposium proceedings. USDA For. Serv., Gen. Tech. Rep. NC-1. North Cent. For. Exp. Stn., St. Paul, Minn.
- Schlaegel, Bryce E., and Stanley B. Ringold.
1971. Thinning pole-sized aspen has no effect on number of veneer trees or total yield. U.S. For. Serv., Res. Note NC-121, 2 p. North Cent. For. Exp. Stn., St. Paul, Minn.
- Smith, Arthur D., Paul A. Lucas, Calvin O. Baker, and George W. Scotter.
1972. The effects of deer and domestic livestock on aspen regeneration in Utah. Utah Div. Wildl. Resour., Publ. 72-1, 32 p.
- Sorensen, Ronald W.
1968. Size of aspen crop trees little affected by initial sucker density. U.S. For. Serv., Res. Note NC-51, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.
- Steneker, G. A.
1972. The growth and management of trembling aspen. Can. For. Serv., North. Res. Cent., For. Rep. 2 (2):5.
- Steneker, G. A., and J. M. Jarvis.
1966. Thinning in trembling aspen stands, Manitoba and Saskatchewan. Can. Dep. For., Publ. 1140, 28 p.
- Strothmann, Rudolph O., and Miron L. Heinselman.
1957. Five-year results in an aspen sucker density study. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Tech. Note 490, 2 p. St. Paul, Minn.
- Weigle, W. G., and E. H. Frothingham.
1911. The aspens: their growth and management. U.S. Dep. Agric., For. Serv., Bull. 93, 35 p.
- Westell, Casey E., Jr.
1956. Ecological relationships between deer and forests in Lower Michigan. Soc. Am. For. Proc. 1955:130-132.
- Zasada, Zigmund A.
1952. Does it pay to thin young aspen? J. For. 50:747-748.
- Zehngraff, Paul.
1947. Possibilities of managing aspen. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Lake States Aspen Rep. 21, 23 p. St. Paul, Minn.
- Zehngraff, Paul J.
1946. How to improve aspen stocking following summer logging. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Tech. Note 251, 1 p. St. Paul, Minn.
- Zehngraff, Paul J.
1949. Aspen as a forest crop in the Lake States. J. For. 47:555-565.
- Zillgitt, W. M.
1951. Disking to increase stocking in aspen stands. U.S. Dep. Agric., For. Serv., Lake States For. Exp. Stn., Tech. Note 357, 1 p. St. Paul, Minn.

The Aspen Forest After Harvest¹

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Abstract.--Aspen is a unique forest tree with respect to regeneration. It produces abundant root suckers, up to 40,000 per acre are common, after clearcutting or fire removes the parent stand. The rapidly growing sucker stand competes well with other vegetation, but is susceptible to destruction by excessive ungulate browsing. Clearcut areas produce more streamflow and more growth on shrubs and herbaceous vegetation than does the uncut forest. The patchwork of age classes that results from even-age management optimizes wildlife habitat requirements for several desired species.

INTRODUCTION

Quaking aspen (*Populus tremuloides* Michx.) occupies perhaps the greatest geographic range of any North American forest tree species. Its ability to regenerate prolifically with root suckers that grow rapidly and successfully compete with other vegetation may have played a major role in establishing this large range. Aspen is a pioneer seral species that colonizes denuded areas. In the northern parts of its range, where growing seasons are relatively short, cool, and moist, regeneration will be by seed and by root suckering. Here, in the southern part, regeneration is almost exclusively by root suckering.

Some speculate that the ortets (seedling parents) of Rocky Mountain aspen clones may have germinated 10,000 or more years ago, when the climate here was more conducive to aspen seedling survival. With periodic wildfire to return the sites to an early seral stage, these aspen were favored and the clones expanded

through many generations of root suckering into the aspen forests we find today in the West, particularly in the central Rocky Mountains.

In relatively recent years man has had considerable impact on the western aspen habitat: (1) His livestock have overgrazed many ranges, which decimated young suckers, especially if they occurred sporadically as advance regeneration in the understory. (2) He has managed big game (deer, moose, and elk) populations to maintain relatively stable numbers near the carrying capacity of the ranges; again, aspen suckers were browsed back repeatedly on many areas. And, most important, (3) he has prevented wildfire from periodically killing the forest, and thus, favoring extensive aspen sprouting.

As a result of these impacts, aspen on millions of acres will be replaced by conifers or by brush and grass within a century. Through proper management this trend can be halted. Harvesting the aspen, and tending the vigorous sucker stands that develop, has been proven through many years of study and experience in the Lake States and adjacent Canada to be an effective way to perpetuate this seral forest type.

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HARVESTING AND POSTHARVEST TREATMENTS

Clearcutting is the only harvesting method that will allow a satisfactory stand of suckers to develop (Baker 1925; Graham and others 1963). Partial cuts result in fewer and less vigorous

suckers and encourage invasion by more tolerant species. The size of clearcut units will be dictated by economics, environmental constraints, and expected browsing pressure by wild ungulates on the developing stand. Silvicultural constraints are minimal; except for a trivial strip along shaded boundaries, sucker regeneration should be uniformly dense across the entire clearcut area (Jones 1975). If a reasonably well-stocked aspen stand is harvested, in most instances the recommended minimum (Graham and others 1963) of 6,000 suckers per acre should be produced. Clearcutting in Arizona resulted in approximately 14,000 sprouts per acre (Jones 1975). Smith and others (1972) found 30,000 to 50,000 sprouts per acre after clearcutting in Utah.

The manner in which felled trees are limbed, bucked, and transported, and their degree of utilization, will affect associated forest resources and the amount and success of aspen suckering. In a Minnesota study (Zasada 1972), the common practice of limbing and bucking at the stump followed by skidding or carrying the logs to haul roads resulted in the least disturbance to the residual stand, understory, and soil when compared to tree-length or full-tree harvesting systems. Limbing at the stump and skidding tree-length logs was intermediate. Most destruction of the residual stand and understory came from a mechanized full-tree system. Mechanically harvesting full trees leaves virtually no residue in the forest. Zasada reported that destruction of the residual stand and understory brush was necessary for successful growth and survival of suckers under Lake States conditions. This can be accomplished at the time of clearcutting, or by subsequent treatment.

A requirement to cut all stems over 2 inches d.b.h. on the clearcut also goes a long way toward assuring an adequate postharvest sucker stand.

Western conditions are different enough that full-tree mechanized systems and maximum site disturbance may not be most desirable. Slopes are steeper and longer and species composition in the aspen understory is entirely different. Erosion potential from these mountainous lands must be more seriously considered than in Minnesota.

Postlogging treatment may be necessary to assure a fully stocked stand of vigorous aspen suckers. Broadcast burning within a year of harvesting will aid in killing understory brush and residual trees (Graham and others 1963; Horton and Hopkins 1966). However, western aspen sites are difficult to satisfactorily burn--burning conditions may not be acceptable during the first or even second

postharvest years. And, if burning is delayed any further the residual parent aspen roots may not re-sucker sufficiently to fully stock the area after the fire (Perala 1974). Fire can be a very useful tool in aspen management, but one that cannot be relied upon.

An alternative to fire is the use of herbicides. Individual unwanted trees may be killed by using a tree injector, or the entire clearcut may be aerially sprayed in late summer (Perala 1971) to kill the residual overstory and brush. Again, spraying must be done within a year or two of harvesting to avoid damage to the suckering capacity of the aspen roots.

ALTERNATIVES TO HARVESTING

It is not necessary to employ the axe, chain saw, or mechanical tree harvester to manage aspen. If the aspen type has sufficient values in the form of wildlife habitat, forage, watershed protection, natural firebreaks, and esthetic qualities to warrant the investment, or if these values plus anticipated future worth in wood products are sufficient, then prescribed fire or herbicides can be used to kill the overstory, retard the brushy understory, and regenerate decadent stands.

A single aerial spraying of 3 pounds per acre of 2,4-D or 2,4-D/2,4,5-T mixture in late summer will accomplish that objective (Perala 1971). The resulting release of a dense brushy understory may require a later re-spraying.

Prescribed burning will effectively kill both the aspen stand and the understory. Excellent regeneration will follow. I recommend it wherever and whenever it can be used. Unfortunately, proper burning conditions are too infrequent in standing western aspen to make this a very reliable technique. The juxtaposition of aspen with much more flammable vegetation types precludes the use of fire as a controllable tool in aspen stands in many mountainous western areas.

TENDING THE GROWING FOREST

Little care is needed once a fully stocked, rapidly growing, even-aged aspen stand has been established. If too dense, the stand will thin itself with little loss in growth due to competition (Perala 1972).

Thinning has been shown to increase production somewhat on saw-log and veneer quality trees (Hubbard 1972; Graham and others 1963), but under western conditions, with questionable economic return.

From the practical standpoint, one can do virtually nothing to prevent or minimize disease and insect damage to the developing forest. Cultural practices, such as thinning, may increase such damage (Perala 1972).

A dense stand of aspen regeneration (40,000 or 50,000 suckers per acre, for example) can withstand considerable browsing. But, this impact must be controlled during the first 10 to 15 years after stand establishment. Aspen suckers are preferred browse by wild ungulates. They can virtually prevent aspen regeneration on winter ranges, and can cause impact on summer ranges, too. Domestic sheep and, to a lesser extent, cattle should be kept out of aspen clearcuts for the first couple years after harvest. Later use should be carefully managed until regeneration is well out of their reach, about 15 feet tall and 2 inches d.b.h.

IMPACTS ON OTHER FOREST RESOURCES

No one value dominates in the aspen type--it truly has multiple values and thus is a multiple use type. A sample of Rocky Mountain forest managers recently placed wild-life habitat as the top value, followed by esthetics and recreation, water, livestock, forage, and wood products in descending order. They felt wood products would become more valuable in the future, but not to the point of dominating management policy. Therefore, the effects of aspen harvesting and management on associated resources must seriously be considered. Only recently have these resources been given their due attention in research on aspen management in the West. Thus, there are limited data upon which conclusions can be based.

Water Quantity and Quality

Water yields will increase about 4 to 6 area-inches from aspen clearcuts (Johnston and others 1969; Johnston 1970; Verry 1972). This increased streamflow will diminish as the new stand occupies the site and probably will disappear within 10 to 15 years from sites satisfactorily regenerated with aspen. The increment to streamflow will occur as base flow and interflow. It comes from more water being retained in the soil mantle at the end of each growing season during the years following cutting, before the upper 6 to 12 feet of soil again become occupied by aspen roots.

There is very little overland flow in an undisturbed aspen forest. Properly done, clearcutting should not increase overland flow appreciably. On sloping lands, at least 65 percent cover of some kind needs to be

maintained (Marston 1952). Serious soil erosion will occur from overland flow if cover is depleted below this level. Some overland flow can be expected from roads and, to a lesser extent, from skid trails. These flows usually can be infiltrated into the forest floor before they reach the stream if the road and skid trail network is correctly designed, located, and properly treated.

Water quality may be slightly altered. Increased flow and the possibility of overland flow from the disturbed area have the potential for increasing stream sediment load. However, if properly conducted, clearcutting should produce very little sediment, and that for only a year or two before the site becomes fully revegetated.

Nutrient cycling is temporarily halted by clearcutting--which may produce an increase in dissolved ions in streamflow. Typically, this will occur as a surge during the first 2 years after harvesting. Prescribed fire is likely to increase the magnitude of this nutrient flush (DeByle, in press). These predicted water quality changes in part are extrapolated from other forest types. Aspen clearcutting, in at least one instance, resulted in no detectable changes in stream-water quality (Verry 1972).

Soil

Except for possible depletion of some plant nutrients with short rotations or with whole-tree utilization over many cutting cycles (Stone 1973; Boyle and others 1973) the soil should not be significantly affected in the long term from careful aspen harvesting. Temporary changes to be expected are decreased amounts of organic matter and total nitrogen and altered contents of available nutrients. These changes are due to increased radiation reaching the forest floor, an altered soil microclimate, less organic debris added annually, and an interrupted nutrient cycle (DeByle 1976). Rapid regeneration of aspen will quickly dampen these effects on good sites (Boyle and others 1973).

If carefully done, aspen clearcutting should not disturb the mineral soil sufficiently to cause significant erosion. Generally, aspen sites revegetate readily; any bared soil again should be protected within a year or two. However, pocket gophers can consume some of the protective mantle of herbaceous vegetation and expose soil to erosion on Rocky Mountain aspen sites (Ellison 1946; Marston and Julander 1961).

Wildlife

Wildlife populations will be affected by aspen harvesting. From man's point of view, most of the effects are favorable. Providing even-aged patches of aspen representing all age classes will benefit deer, moose, elk, and grouse. Browse for ungulates is present in abundance during the early years (Graham and others 1963; Byelich and others 1972) and grouse habitat is best if all aspen age classes are present in close proximity (Gullion and Svoboda 1972). Aspen browse and leaves are often the most abundant components of deer diets (McCaffery and others 1974; Julander 1952). Clearcut harvesting of eastern hardwoods and the resulting even-aged regeneration provide nesting habitat for a greater diversity of bird species than no cutting (Conner and Adkisson 1975). Beaver almost exclusively use aspen and other closely related species for food and dam building (Bailey 1922). In short, merely keeping a diversity of habitats and maximum of edge through maintaining and managing the aspen type will benefit many wildlife species.

Forage and Understory Production

The production of forage as well as the composition and production of all understory plants will be influenced by aspen harvest. There is a paucity of data from the West in this regard. Ellison and Houston (1958) found increased production of selected species in openings and on trenched plots under aspen as compared to plots under undisturbed aspen forest. More recently, research being conducted by the Intermountain Forest and Range Experiment Station indicates what will happen to production during the first year after clearcutting or after burning.

A year after aspen clearcutting in northern Utah approximately 1,850 pounds per acre was produced as current year's growth on shrubs, forbs, grasses, and annuals on cut plots as compared to roughly 1,600 pounds per acre under the undisturbed aspen canopy. A year of precut sampling showed about 100 pounds per acre less production on the plots to be clearcut than on the controls. Thus, there is indication of an increase of 300 to 400 pounds per acre following cutting.

Because of damage to the understory, burning an aspen stand in northwest Wyoming in 1974 produced the opposite results. Production of grasses, forbs, and especially shrubs was markedly decreased. Prior to burning in 1974 there was 1,550 pounds per acre production on the control plots as compared to 1,265 pounds on the plots to be burned, a difference of

18 percent. In 1975 there was 2,012 pounds per acre production on the controls and only 925 pounds on the burned area, a difference of 54 percent.

In both instances, these are only first-year results. The temporary setback in understory production after burning could be negated by high production in succeeding years. The understory reduction from fire favors aspen sucker production during the first few postburn years.

Esthetics

Esthetics will be improved in the long run, but perhaps adversely affected in the short run, by managing and harvesting aspen. Harvesting requires roads for access. To minimize several adverse impacts (erosion, stream sedimentation, visual impact, and unwanted and uncontrolled public access), these roads should be minimal in number and closed and "put to bed" when not needed.

Clearcutting causes adverse visual impact in any forest type. Fortunately in aspen, because of the lush, rapid-growing understory, this impact is minimal and short-lived. Keeping the clearcut patches small and irregular in shape will reduce the visual esthetic impact.

Harvesting, and thus maintaining aspen as a forest type in juxtaposition with conifer forests, brushlands, and grasslands will maintain and improve the amenity of the western mountain landscape. The alternative is to erase much of the aspen from these landscapes within a century through succession to conifers or brushlands.

SUMMARY

On most sites aspen is a seral species, dominating the community for a span of 50 to 200 years or more. Harvesting the aspen forest by clearcutting on approximately 80- or 90-year cycles will set back the successional process and maintain the aspen type on sites where it is desired. The alternatives to clearcut harvesting (fire or herbicides) will accomplish the same objective, but do not utilize the wood. For economic reasons, it is doubtful that much aspen acreage will be managed without wood utilization.

The ideal aspen clearcut several years after harvesting will have about 12,000 vigorously growing sprouts per acre. For the following decade or more it will provide an abundance of browse for big game, will yield a third of a foot more water than the mature aspen

stand, and will be visually acceptable or even pleasing as part of the landscape. During the first year or two after harvest the quality of streamflow may be slightly lowered with dissolved nutrients and sediment. The soil and site are disturbed by the harvesting process, but they rapidly return to preharvest conditions as the aspen suckers again develop a closed forest canopy.

Within 2 decades after harvesting a good site will have essentially returned to the conditions found in a mature aspen stand. Breeding grouse habitat is ideal in these pole-sized stands, increment of wood is now at its peak, and the forest appears most vigorous.

From about 30 years to the end of the cutting cycle at 80 or 90 years, the aspen forest continues to grow and to naturally thin itself to some 300 to 600 stems per acre. Shade-tolerant tree species, such as spruce and fir, begin to invade the stand. It is essentially a mature aspen forest with respect to all resources except wood production. When it matures for production of wood, the stand is clearcut and the cycle begins anew.

LITERATURE CITED

- Bailey, Vernon.
1922. Beaver habits, beaver control, and possibilities in beaver farming. U.S. Dep. Agric. Bull. 1078, 32 p.
- Baker, Frederic S.
1925. Aspen in the central Rocky Mountain Region. U.S. Dep. Agric. Bull. 1291, 47 p.
- Boyle, James R., John J. Phillips, and Alan R. Ek.
1973. "Whole tree" harvesting: nutrient budget evaluation. J. For. 71(12):760-762.
- Byelich, John D., Jack L. Cook, and Ralph I. Blouch.
1972. Management for deer. In: Aspen Symposium Proc., p. 120-125. USDA For. Serv. Gen. Tech. Rep. NC-1.
- Conner, Richard N., and Curtis S. Adkisson.
1975. Effects of clearcutting on the diversity of breeding birds. J. For. 73(12):781-785.
- DeByle, Norbert V.
In press. Soil fertility as affected by broadcast burning following clearcutting in northern Rocky Mountain larch-fir forests. Fire and Land Management Symposium Proc., Missoula, Montana.
- DeByle, Norbert V.
1976. Fire, logging, and debris disposal effects on soil and water in northern coniferous forests. XVI IUFRO World Congr. Proc., Div. 1, p. 201-212.
- Ellison, Lincoln.
1946. The pocket gopher in relation to soil erosion on mountain range. Ecology 27(2):101-114.
- Ellison, Lincoln, and Walter R. Houston.
1958. Production of herbaceous vegetation in openings and under canopies of western aspen. Ecology 39(2):337-345.
- Graham, Samuel A., Robert P. Harrison, Jr., and Casey E. Westell, Jr.
1963. Aspens: phoenix trees of the Great Lakes region. The Univ. Mich. Press, Ann Arbor. 272 p.
- Gullion, Gordon W., and Franklin J. Svoboda.
1972. The basic habitat resource for ruffed grouse. In: Aspen Symposium Proc., p. 113-119. USDA For. Serv. Gen. Tech. Rep. NC-1.
- Horton, K. W., and E. J. Hopkins.
1966. Influence of fire on aspen suckering. Can. Dep. For. Publ. 1095, 19 p.
- Hubbard, John W.
1972. Effects of thinning on growth and yield. In: Aspen Symposium Proc., p. 126-130. USDA For. Serv. Gen. Tech. Rep. NC-1.
- Johnston, Robert S.
1970. Evapotranspiration from bare, herbaceous, and aspen plots: a check on a former study. Water Resour. Res. 6(1):324-327.
- Johnston, Robert S., Ronald K. Tew, and Robert D. Doty.
1969. Soil moisture depletion and estimated evapotranspiration on Utah mountain watersheds. USDA For. Serv. Res. Pap. INT-67, 13 p.
- Jones, John R.
1975. Regeneration on an aspen clearcut in Arizona. USDA For. Serv. Res. Note RM-285, 8 p.
- Julander, Odell.
1952. Forage habits of mule deer during the late fall as measured by stomach content analyses. U.S. Dep. Agric., For. Serv. Intermt. For. and Range Exp. Stn., Res. Note 2, 5 p.
- Marston, Richard B.
1952. Ground cover requirements for summer storm runoff control on aspen sites in northern Utah. J. For. 50(4):303-307.
- Marston, Richard B., and Odell Julander.
1961. Plant cover reductions by pocket gophers following experimental removal of aspen from a watershed area in Utah. J. For. 59(2):100-102.
- McCaffery, Keith R., John Tranetski, and James Piechurs, Jr.
1974. Summer foods of deer in northern Wisconsin. J. Wildl. Manage. 38(2):215-219.
- Perala, Donald A.
1971. Aspen successfully regenerated after killing residual vegetation with herbicides. USDA For. Serv. Res. Note NC-106, 2 p.

Perala, Donald A.

1972. Regeneration: biotic and silvicultural factors. In: Aspen Symposium Proc., p. 97-101. USDA For. Serv. Gen. Tech. Rep. NC-1.

Perala, Donald A.

1974. Prescribed burning in an aspen-mixed hardwood forest. Can. J. For. Res. 4:222-228.

Smith, Arthur D., Paul A. Lucas, Calvin O. Baker, and George W. Scotter.

1972. The effects of deer and domestic livestock on aspen regeneration in Utah. Utah Div. Wildl. Resour., Publ. 72-1, 32 p.

Stone, Earl.

1973. The impact of timber harvest on soils and water. In: Report of the President's advisory panel on timber and the environment, April 1973, p. 427-467.

Verry, Elon S.

1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. In: Watersheds in Transition Symp. Proc., p. 276-284. AWRA, Ft. Collins, Colo.

Zasada, Z. A.

1972. Mechanized harvesting systems can aid management. In: Aspen Symposium Proc., p. 131-136. USDA For. Serv. Gen. Tech. Rep. NC-1.

Response Of Aspen To Various Harvest Techniques¹

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Abstract.--Aspen is an important component of both the Engelmann spruce/subalpine-fir and the Douglas-fir/white fir types. On all recent San Juan National Forest sales, aspen has been part of the included timber. Harvesting responses differ for three situations - aspen is a mature part of a coniferous overstory; aspen is an overstory with a fully stocked coniferous understory; aspen is a pure stand with no coniferous mixture. Effects of grazing, residue volume, and cutting intensity are considered.

Commercial aspen type occurs on 269,000 acres or 21% of the commercial forest land on the San Juan National Forest. Within the aspen type, approximately 20% of the cubic foot volume of the stands is associated softwoods. Of the 269M acres of aspen type, 66.5M acres are classed as sawtimber, 119M acres are classed as poletimber and 85.5M acres are seedling-sapling or non-stocked.

Analysis of the stand age data indicates that many of the stands reach rotation age without growing to sawtimber size. Hinds has recommended a rotation of 80 to 100 years in the Rocky Mountains. There are 89.5M acres over 100 years old. For this to happen, at least 23M acres of pole timber must be over rotation age.

Aspen also occurs as a component in the conifer types. Within the spruce-fir sawtimber type, aspen represents 5% of the cubic foot volume, or 3% of the board foot volume of the stands. In the Douglas-fir--white fir sawtimber stands, aspen represents 11% of the cubic foot volume or 7% of the board foot volumes of the stands. Aspen is almost totally absent from the ponderosa pine type, representing less than 1% of the cubic foot volume of these stands.

During the previous 10 years, the San Juan has harvested an average of 4.1 MBF per year of aspen sawtimber. There are only minor markets for products other than sawlogs. The cut of aspen sawlogs has not been a major part of the Forest harvest, representing only 5½% of the total sawlog harvest. While aspen is not a major part of our harvest, we have not entirely ignored the silvicultural management of the type.

On all of the recent timber sales on the San Juan, aspen has been a part of the included timber. Falling and removing of designated aspen is required on these sales. The more recent timber sales in the spruce-fir type, and the Douglas-fir--White-fir type, have generally received an intermediate cut or a first-stage shelterwood cut. These sales have been individual tree marked. No attempt has been made to eliminate aspen as a component of these stands. When mature aspen trees are encountered, they are marked for removal. Because of differences in rotation age between aspen and conifers, and because the aspen is often residual trees on sites that have converted to conifers, the harvest of aspen from these stands is frequently greater than the part of the stand in aspen. Conifer sales containing 10-15% aspen volume are not uncommon.

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Aspen has responded well to this treatment. There are sufficient overstory conifers to maintain the conifer type. Small openings have regenerated to aspen. Thus aspen will continue to be an important component of these stands.

Aspen occurs as an almost pure overstory in stands with full stocking of conifer understory. We have made overwood removal cuts in these stands, removing all aspen over 8" DBH

(fig.1). The response has been favorable. The conifers have increased both in diameter and height growth. Due to irregularities in stocking or to logging damage, the conifer reproduction seldom fully occupies the site. Where openings occur, aspen reproduction has been quite abundant (6,000-10,000 trees per acre). Aspen will continue to be a strong component of these stands but the future stand will probably be typed as a conifer stand.



Figure 1.--Aspen overwood removal two years after harvest.

Aspen also occurs in essentially pure aspen type. There have been a variety of harvest techniques in these stands. In the mid 1960's, a sale was let where only the merchantable trees were felled and removed. Later sales in the late 1960's required all trees over a given diameter (either 8" or 10") to be felled and removed. The response to this type of harvest is directly related to the amount of residual stand left after harvest. The most recent sales in this type have required that all aspen trees over 2" DBH be felled. Falling unmerchantable trees can either be the purchaser's responsibility, under the terms of the timber sale contract, or can be done by the Forest Service with deposited KV funds.

A series of aspen cuts made in 1965 and 1966 is worthy of mention. These stands were decadent at the time of harvest. Only merchantable trees were felled. This resulted in a residual stand of decadent trees and very light slash on the ground. The area has had unrestricted cattle use since harvest. Today, these areas have essentially converted to grass. Because of the partial cut, aspen reproduction was weak. Data are not available, but reproduction was probably about 1,000 trees per acre. The overstory undoubtedly suppressed

the height growth of these trees. Cattle browsing and trampling damaged what reproduction did occur. Today there are no reproduction trees which can be considered as potential crop trees. This system of management is not recommended if the intent is to produce crops of aspen. However, it appears to have merit if the intention is to reduce the area of aspen and increase the area of rangeland.

Other areas cut to a minimum diameter limit, usually 10" DBH, have responded well and are now overstocked with potential crop trees. These stands were not decadent at the time of harvest. Generally, there were sufficient trees of merchantable size that a relatively light residual stand was left. Regeneration occurred and height growth has not been retarded. Residual basal area appears to have been in the range of 30 to 60 square feet per acre. Some of these stands have now been recut to remove the residual trees from the original harvest. This recut is only one or two years old but it appears that the damage to the 10-15 years old reproduction is within acceptable limits. New sprouting is occurring in openings in these stands.

Some, but not all, of the areas cut in the 1960's have received moderately heavy grazing use. The trees in these areas appear sound and well formed. Browsing was not heavy enough in these stands to restrict height growth. The trees are now 10 feet or taller and above any browsing damage. However, many of these trees show signs of basal scars, probably caused by trampling. Most of these basal scarred trees have a discoloration of the heartwood. The pathology lab has identified this as an unknown stain causing fungus. Whether or not this fungus will prevent the trees from producing usable sawlogs remains to be determined.

The most recent sales in pure aspen type have been true clearcuts. All aspen trees 2" DBH and larger have been felled. The response to this treatment has been impressive. Sprouting has occurred at the rate of 6,000 - 10,000 stems per acre. In the second growing season, dominant trees are 6 feet tall (fig.2). There is only minor sign of wildlife browsing and no cattle damage. None of the trees yet show any sign of the unidentified stain-causing fungus. Because all of the trees were felled, the areas are more pleasing visually (fig. 3); the ragged appearance following commercial clearcutting is absent. The unmerchantable debris on the ground has created a barrier which discourages cattle use (fig. 4). Although this debris is now serving a useful purpose of discouraging animals use, it remains to be seen if this debris will also discourage future silvicultural activities in the stand.



Figure 2.--Aspen clearcut second growing season after harvest.



Figure 3.--Aspen clearcut second growing season after harvest.



Figure 4.--Aspen clearcut two weeks after harvest.

Harvesting and obtaining regeneration is not an end in itself. Once regeneration is established, the new stand must be properly tended. Various research studies, along with local observations, show that unrestricted browsing and trampling can destroy a new sprout stand. Therefore, some measure must be taken to restrict this usage. In most cases, complete protection is not practical and probably is not necessary. The key seems to be restricted use, either by range management practices or by leaving sufficient debris so as to discourage animals from using the area.

There is a wide spectrum of opinion regarding the desirability of precommercial thinning in aspen stands. Research papers can be found which support both sides of the question. I consider that pre-commercial thinning is desirable on the San Juan. Our management is based on sawtimber production. Many wild stands have reached rotation age while still in the poletimber size class.

The foregoing is based on several years' observation of aspen response on the San Juan. Unfortunately, exact numerical data are not available.

Table 1.--Area of commercial forest land on the San Juan National Forest

Type	Acres
Spruce-fir	421,021
Ponderosa pine	342,548
Douglas-fir-white fir	231,529
Aspen	268,864

Table 2.--Area of aspen by stand size class

SSC	Acres
Sawtimber	66,505
Pole timber	118,703
Seedling-Sapling	23,634
Non-stocked	60,022

Table 3.--Area of aspen by age class

Age Class	Acres
0-20	60,022
21-40	14,209
41-60	67,844
61-80	33,624
81-100	3,623
101-120	25,498
121+	64,044

Table 4.--Cubic-foot volume of aspen in sawtimber stands, by timber type

<u>Type</u>	<u>MCF</u>
Spruce-fir	64,470
Ponderosa pine	1,888
Douglas-fir--white fir	43,933
Aspen	<u>108,301</u>
	218,592

Table 5.--Board foot (Scribner) volume of aspen in sawtimber stands, by timber type

<u>Type</u>	<u>MBF</u>
Spruce-fir	226,514
Ponderosa	-0-
Douglas-fir--white fir	111,479
Aspen	<u>337,600</u>
	675,593

Table 6.--Board foot (Scribner) volume per acre of aspen in sawtimber stands, by timber type

<u>Type</u>	<u>BF/A.</u>
Spruce-fir	590
Ponderosa pine	-0-
Douglas-fir--white fir	570
Aspen	5076

Table 7.--Board foot (Scribner) volume of aspen and percent of total cut in the past decade

<u>CY. Year</u>	<u>MBF Cut</u>	<u>% of Forest Harvest</u>
1966	6,692	7.5
1967	3,440	3.7
1968	2,489	2.4
1969	4,219	5.5
1970	3,913	5.5
1971	3,452	4.8
1972	3,874	5.5
1973	5,371	7.8
1974	4,591	8.2
1975	3,372	8.1

Ten Year Average: 4,141

Panel III.

**Market Opportunities And Limitations
For Rocky Mountain Aspen**

Moderator: Garrett Blackwell

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and Utilization
New Mexico Department of
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Lumber Markets For Rocky Mountain Aspen¹

Gordon K. Runyon²/

SUMMARY

At present, Rocky Mountain aspen is just being sold, not marketed. In only one case, "Great Scot" paneling, has there been any real market planning. The marketing plan should assure that when trees are logged, the operator knows where the wood is going.

For the past decade, Rocky Mountain Aspen has been marketed primarily as box and crating lumber. Even though aspen has been recently marketed as shakes, paneling, decking, and studs it has not generally been accepted as a substitute for the species now being used in these products. Several mills are now experimenting with new products, including new paneling designs, shakes, tongue and groove decking, and studs.

¹/ Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, September 8-9, 1976.

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The biggest problem in processing and marketing aspen lumber products is the poor quality of drying that can be, or is being achieved by the mills at present. A second barrier is not being able to provide a consistent supply of aspen products. Another is failure to take advantage of already established markets in the eastern U.S.

Aspen Market Opportunities: Lumber, Excelsior, And Residue¹

Mark S. Koepke^{2/}

ABSTRACT,--Rocky Mountain aspen is presently being marketed for lumber, excelsior and residue products. These include pallet stock, paneling, sawn mine material, excelsior, match sticks, novelty items, firewood and sawdust. This paper discusses these plus industries that didn't make it and future markets.

Aspen is truly an untapped resource in the Rocky Mountains. However, in order to utilize a resource, markets must be developed and profit obtained. The inability to find these markets has been one of the major hinderances to the utilization and proper management of aspen in the Rocky Mountain States. Aspen is used heavily in the Lake States for numerous products, so it can be a viable source of wood fiber. The question is, how can it be made economically viable in the Rockies?

Information within this paper was gathered through contacts in both industry and government. The mention of company names is not intended to promote that particular company or its products, but provide examples. In the same way, if certain companies producing aspen products are omitted, please understand no offense was intended. Also, in the Beehive State of Utah, sometimes those rascals deposit a waxy substance in your ears. Therefore, take the information, especially prices, with this in mind.

It seems logical, in order to sell a product, you ought to know what you're selling. Aspen traditionally has had a poor name, because it has not been properly sold in regard to its unique characteristics. For instance, a piano company tried to use aspen for a part demanding numerous screw holes.

It was applied without knowledge of its inferior nail-holding ability. Thus, by not using more, and possibly larger screws, aspen failed. Although characteristics may be covered in other papers, let's take a look at aspen from a marketing standpoint.

Aspen is a fine-grained, light, soft hardwood. The color is white to light brown. It is odorless when dry, tasteless, non-resinous, and resistant to splitting (especially end-splitting when nailed). The wood is fairly dimensionally stable after drying. Gluing qualities are excellent, according to The Wood Handbook. Aspen also has good printability. Its strength can be compared with basswood, with the wood excelling in toughness.

Aspen also has its problems. The trees themselves cause milling problems because of recurrent crook and sweep. Aspen is also susceptible to much disease, causing stain, heart rot and bole misformation. Wengert (9) says an average log yields 15% bark, 45% sawdust and residue and 40% lumber (15% upper-grades, 85% lower). It will be necessary to find stable markets for lower grades and residue, to keep operations profitable.

Other problems with aspen include drying. Wetwood in aspen dries very slowly, making air drying almost a necessity, before kiln drying. Poor drying techniques are accentuated in aspen by showing large amounts of drying degrade. Nail-holding qualities are poor, however, larger or different nail designs improve this markedly. The wood also deteriorates quickly. Aspen machines easily. It will tear and fuzz, though, when proper turning speed and sharp knives at the correct angle are not maintained. These are not all of aspen's characteristics, but keeping these few in mind, marketing aspen is the next step.

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, September 8-9, 1976.

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ASPEN LUMBER

Preliminary data concerning the volumes of aspen harvested in Rocky Mountain States during 1974 have been computed. In Utah, Colorado, New Mexico and Arizona aspen sawlogs ranked first in volumes cut. The majority of the lumber produced from these sawlogs went into pallets, paneling and mine materials. Hardly any Rocky Mountain aspen is used in construction lumber. Presently, aspen lumber products provide a wide market potential and, generally, the highest return, when compared to other aspen uses.

About 12.7% of the lumber produced in the U. S. during 1975 goes into pallets. By 1985, 400 million pallets will be needed (2). Aspen pallets use much of the aspen now harvested in the Rockies. Dr. Walter B. Wallin, at the Forest Products Marketing Laboratory in Princeton, West Virginia in cooperation with Dr. E. George Stern at VPI, have been studying aspen pallets for some time. Dr. Stern has written three excellent publications on design and strengths of aspen pallets (5,6,7). In August of 1975, Dr. Wallin (8) wrote me a letter saying:

"To date, aspen has not been widely accepted for permanent pallets for several reasons:

1. To obtain a pallet which will provide equivalent performance to an oak pallet (60 percent of our hardwoods in the East are oaks) requires stringers 3 inches wide in aspen in lieu of 1-3/4 inches in oak.
2. To provide equal-strength joints, the nails used in aspen should be 3" by 0.120"; and there should be six nails per 6-inch deckboard joint and four nails per 4-inch joint. In oak, 2-1/4" by 0.110" size with three per 6-inch and two per 4-inch joint.
3. The cost differential between aspen lumber and oak lumber has not been sufficient to justify the increased footage and increased nailing.

4. In the East, pallet producers and pallet users have become accustomed to processing and using the 1-3/4 inch stock, and they are reluctant to make the changes in their processing.
5. In the past, attempts to use aspen, pine, fir and other softer species have been made with no compensation in size or fastenings when the softer species were used. As a result, the performance was bad; and most users will not accept soft species readily, if at all.

I am convinced that pallets can be produced from aspen or cottonwood which will perform as well as the oak pallets..."

One pallet company in Denver that uses quite a bit of aspen is Denver Reel and Pallet Company. Quoting another letter, Mr. Karl Heimbrock (3), President of Denver Reel and Pallet Company, writes:

"Our purchases are random length, approximately 80% 1x6 and 20% 1x4, green S2S to 7/8" in a 4 & BTR grade. Aspen is used only for deckboards, lead and otherwise. Our 2x4's or stringers are mixed white woods due to their superior nail-holding capabilities. Aspen is used primarily in the manufacture of permanent warehouse type pallets but is also used in expendable or one-way pallets where greater strength is required. We are purchasing aspen wherever it is available..."

Therefore, aspen, used for pallets, has an excellent market potential, if it is used properly. Two things to note in Mr. Heimbrock's letter, 1) grades down to a #4 can be utilized, and 2) no special nailing procedure is necessary, if the aspen is used only for deckboards.

Solid paneling is another product produced from aspen lumber. The largest producer is Great Scot Timber and Logging

Company, Englewood, Colorado. Great Scot, who's mill is in Bayfield, Colorado, makes a tongue-and-grooved, about 1/2" board; four or six inches wide, in random lengths up to eight feet. They purchase green 6/4 and 5/4, #1, #2 and #3 commons, then dry it to 7% in their kiln. High grades of boards are too plain, and lower grades may have loose knots or larger defects. No wane or rot is allowable in paneling. Great Scot buys their lumber on the open market, but have not been completely satisfied with quality control or availability of Rocky Mountain aspen. In fact, on some occasions, they have purchased Lake State's aspen. They hope to utilize 5MMbf of aspen this year.

After drying, resawing, planing, shaping, cutting-off and possibly, staining takes place. One side is planed; the other is left rough, for a tweedy look. In Utah, the paneling runs between \$.55 and \$.70 a square foot for natural, and may go as high as \$.80/ft² for stained. Markets for aspen paneling are nationwide.

Another use of the paneling is in the sauna bath business. Aspen is used in place of redwood because, 1) no splinters, 2) no staining with sweat, 3) very small dimensional changes in the changing environments, and, 4) it's cheaper. The sauna bath is completely lined with aspen, then controls, and possibly redwood floors and benches are added. A sawmill in Utah sends all their green, rough 8', 8/4 selects and clears to California for this product. Great Scot paneling is also sometimes used. Retail prices run about \$.90 a square foot for sauna paneling. Paneling out of aspen appears to be a very viable market, but provides limited use of the total aspen tree, because of the grades needed.

Mine cribbing, caps, wedges, and washers are also made from aspen lumber. Cribbing is squared 4x4's and larger, about 30 inches long. They can be as large as 12x12". In long-wall coal mining, these blocks of wood are built into a square shape from floor to ceiling, in order to keep ventilation and access shafts open. Wedges are tapered boards of various widths and lengths. They are used to tighten fits on the tops and bottoms of cribs and between props and caps. Caps are short blocks of 4x4's used on top

of props, to butt up against the roof or floor. Washers, also called "holy boards", are 2x8's, 2x10's and 2x12's, with a hole drilled in the center. These are used with a continuous miner (digging a tunnel). The washers work in conjunction with roof bolts to support the ceiling.

Kilborn (4), in an unpublished USFS paper, says an average of 1.25 board feet of sawed material is needed for each ton of coal produced in Utah. By 1985, just Utah should be mining 36 million tons of coal needing 45 million board feet of sawed material. Aspen can be utilized for mine material. Market prices run about \$.80 for a 4x6x30" crib (\$160/Mbf) about \$.25 for a 2x6x18" wedge (\$167/Mbf), and, between \$.35-\$.45 for a 2x8x18" washer (\$200/Mbf). The possibilities of this market for aspen is tremendous. It is an especially good market because mines accept green material, with discoloration, some punk and fairly large knots. Cribbing particularly helps to utilize low grade centers of aspen trees.

Residue produced from aspen lumber is not utilized to any great extent. One mill in Utah tries to sell the sawdust for animal bedding (clean, odorless, splinterless and very absorbent), and the slabs for firewood. Most mills, however, still burn it or, where that is illegal, pile it. Mills in New Mexico and Colorado may have a use for it, I don't know.

EXCELSIOR MARKETS

In the 1974 Rocky Mountain harvesting data, aspen cut for excelsior was almost equal to that cut for lumber in the States of Utah, Colorado, New Mexico and Arizona. Excelsior is used in cooler pads, packaging and cover mats for reseeding along road cuts. By far the largest purchaser of aspen for excelsior in the Rockies is AMXCO (American Excelsior) headquartered in Arlington, Texas. They own a total of five mills - two in Wisconsin, one in California, one in Cedar City, Utah and one in Englewood, Colorado. There are also two or three independant mills in Colorado.

AMXCO contracts out all their cutting. The mill in Cedar City accepts tree length

logs, and 100-inch peeled and unpeeled bolts. The company pays \$36/cord for peeled sticks, and \$25/cord for unpeeled. The wood is dried nine months to a year before being cut into 18" blocks. Excelsior machines can handle diameters up to 20" and down to 6". Clear, unstained aspen is most desirable, however, some defect can be tolerated. Residues of bark, sawdust and small slabs of wood are produced during the manufacturing process. In Cedar City, the bark and sawdust is hauled to the dump, and the wood is given away for firewood. Although excelsior markets fluctuate constantly, excelsior will provide a continued use of Rocky Mountain Aspen.

MATCH STICKS

The Ohio Match Company has a match stick plant in Mancos, Colorado. They harvest 1-2 million board feet of aspen per year; but are unable to utilize all of it. The problem stems from the fact that they are unable to accept any rot, discoloration and diameters smaller than 8". This is because of stringent strength tests required of the matches, plus, the problem of lathe size requirements and spin-out. Ideal bolt size is 14-16 inches in diameter. The plant produces about 25 million splits (or match sticks) /day. Match splits will continue to provide a market for aspen, but does not appear to show any potential for future growth.

Residue in match split production is produced from rejected logs, bark, veneer cores and split rejects. Presently, Ohio Match's low quality logs are shipped to an excelsior mill. Some veneer cores are utilized for excelsior, however, most cores are sent to California for furniture legs. Some cores also end up on plastic longhorn horns produced by a Texas firm, and some goes for firewood. All other residue is burned to fire the boilers.

NOVELTY ITEM MARKET

Recently, as many as six new firms have been established in marketing aspen tourist type items. All of these companies seem to be in Colorado. Most utilize standing dead material (sooty bark) and/or

sick green (*Fomes ignarius*) to obtain the interesting colors and designs in the wood. Items are turned, sawed and left in the round. They include things like mushrooms, candleholders, and little forest scenes set in cross sections. A few companies are also expanding into bed posts, vases and lamp stands. Presently, volumes utilized are quite small and come off of Forest Service and private lands. A company in Rollinsville, Colorado, makes jewelry items with aspen leaves that have been dipped in gold or silver. Another, in Loveland, shoots dye into young saplings, then uses the colored wood for jewelry. Mr. Bob Dyans (1), of Aspen Wood Products, Evergreen, Colorado says that aspen sells for emotional reasons. He feels people like to hear that only dead trees are cut (ecology), that every piece is hand-crafted, and that people can relate aspen to a good experience they had in the Rockies. He has a good point, and this use of aspen has potential, especially using low grade trees.

PRODUCTS THAT DIDN'T MAKE IT

Mink Bedding

In the Rocky Mountain region, mink bedding is a relatively new product being produced from aspen. Utah has the second mill in the country which specifically makes this bedding. The other one is in Wisconsin. The product is a fibrous, shredded material that is sold by the sixty-five pound bale for between \$2.35 - \$3.00. The bedding is used by mink farmers to clean the pelts a few months before killing, and to provide nesting material for the kits. Aspen is the preferred species because it is non-resinous (for clean pelts), and it is splinterless (small splinters get in the kits eyes and blind them).

Aspen bolts 7'9" long are needed for Utah's mink bedding operation. Originally, it was thought that the production of bedding would help use small diameter, crooked stemmed aspen however, the operator found straight bolts, about 10" in diameter, were the most efficient. Production machinery consists of a shredder, dryer, bulk storage facilities and baler. The shredder is a large box moving hydraulically across

spinning, toothed rollers. There is no residue left from the bolts, though a fine dust is blown off during drying. Markets for the bedding included all the western states. Also, because the facility was capable of producing more bedding than demanded, the pet bedding market was explored. This potential market looks very good, unfortunately, the operator went out of business before it could be tried.

Marketing the fine dust residue, produced at the dryer, was another problem. A company which sells mud for oil well drilling bought some for \$.12 a cubic foot. The operator felt this was a rather poor return. Other markets were mulch material (mix with mink droppings and let set for a year - market value \$30-50/cu. ft.), hydromulch (worked fine, except needed tracing color - market value \$122/ton), and wood flour as a glue extender (samples were sent for analysis). Once again, bankruptcy halted further investigations.

The mink bedding operator went out of business for a number of reasons. Of primary importance was the harvesting of the aspen. There were many hidden costs, such as tires, road grade (even on established roads), aspen's variability, saw breakdowns, etc., of which he was not aware. Also, because he was only the second of a kind, capitol expenditures and machinery inefficiencies and breakdowns at the mill were excessive. The Utah Mink Growers Co-op has taken over the mill and, production may again start. The potential market for aspen bedding appears to be good, if the harvesting problems can be worked out.

Door Cores

In 1965, San Pete Forest Products Company opened in Ephraim, Utah. The company planned to produce door cores out of aspen. Timber was made available by the U. S. Forest Service and markets were established. But in 1966, San Pete went out of business. The problem: harvesting costs were too high and not enough timber was brought in during the summer to carry them through the winter. Again, potential is there, but harvesting not economical.

Snow Fences

In 1975, a snowfence company was interested in moving to Utah to make aspen fencing. After working out all the locations, financing and marketing problems, the aspen resource proved to be the stopper. The biggest problem with the aspen seemed to be lack of information on quality and quantity of the resource. No volumes could be guaranteed to the company from U. S. Forest Service, State or private lands because they were not known, especially, in regards to land use planning. Defect was also not able to be determined. Therefore, again, markets were available, but the aspen itself proved to be the detrimental factor for an investment.

FUTURE MARKETS

In the short run, future markets of Rocky Mountain aspen still seem to be best in sawn material. Products such as pallet stock, paneling and mine material will continue to use larger volumes and provide good returns. As was mentioned earlier, mine material probably has the best potential in the expanding coal industry. A big plus for this market is the ability to use lower grade material, which makes-up much of our present aspen stands. Large expected demands for pallets will also make harvesting more economically desirable. Regional demand for pallets will be able to utilize much of the production. This is especially true in Utah, where desirable taxation is promoting large warehouses.

Long run markets need to be further developed, however, there is good potential. One mill in Colorado wants to try aspen shingles. Higher grade boards could go into cash-and-carry stores for shelving. Aspen used for hidden furniture parts is also a potentially good market. The export of aspen logs or products to Japan must also be explored. The Japanese have been buying some aspen logs in British Columbia for furniture stock.

Residue markets also need further exploration. Bedding for livestock from aspen sawdust and planer shavings is

excellent, and should be promoted. Mulching, also seems marketable, especially in light of aspen's rapid breakdown. Aspen residue has good potential in hydromulching and wood flour. These markets, however, would call for some capital expenditure in machinery to breakdown residue into finer particles.

All-in-all the potential of utilizing Rocky Mountain aspen is good. Economics of harvesting will play a key role in determining utilization. It must also be stressed that aspen be sold with its characteristics in mind, otherwise aspen's bad name will continue.

LITERATURE CITED

- (1) Dynes, Bob.
1976. Interview with Mr. Dynes
8/12/76. Aspen Wood Products,
2356 Hiwan Drive #41, Evergreen,
Colorado.
- (2) Heimbrock, Karl R.
1976. The Future of the Pallet
Industry in the Rocky Mountain
Area. Rocky Mountain Forest
Industries Conference. April
26-28, 1976. Missoula, Montana.
- (3) Heimbrock, Karl R.
1976. July 14 letter from Mr. Karl
Heimbrock, President of Denver
Reel and Pallet Company, 4600
Monaco Parkway, Denver, Colorado
80216.
- (4) Kilborn, Ken.
1976. Wood Used in Coal Mining.
Unpublished Region 4, U. S. Forest
Service paper.
- (5) Stern, George E.
1974. Design of Pallet Deckboard -
Stringer Joints Part I: Aspen-
Pallet Joints and Aspen Pallets.
Virginia Polytechnic Institute
and State University. Wood
Research Bulletin No. 126.
(Write to VPI & SU, Dept. of Forest
and Wood Products, Blacksburg,
Virginia 24061.
- (6) Stern, George E.
1975. Design of Pallet Deckboard -
Stringer Joints Part II: Reinforced
Aspen Pallet Joints and Aspen
Pallets. VPI & SU. Wood Research
Bulletin No. 133.
- (7) Stern, George E.
1975. Aspen Pallets with 2 1/4",
2 1/2" and 2 3/4" - wide Stringers
and Aspen Pallets with Oak Stringers
and Leading-edge Deckboards. VPI
& SU. Wood Research Bulletin
No. 135.
- (8) Wallin, Walter B.
1975. August 26 letter from Dr.
Wallin, Wood Technologist, Forest
Products Marketing Laboratory, P. O.
Box 152, Princeton, West Virginia
24740.
- (9) Wengert, Eugene M.
1974-1976. Numerous conversations
with Dr. Wengert, Extension
Specialist, Dept. of Forest and Wood
Products. VPI & SU.

Market Opportunities And Limitations For Rocky Mountain Aspen¹

Eugene M. Wengert^{2/}

SUMMARY^{3/}

The potential for any large use of Rocky Mountain aspen lumber is limited by (1) high processing costs (2) market limitations imposed by grading rules, (3) high transportation costs to most market areas. As these problems are solved, the outlook should improve. Small market niches do exist at present and can be expanded; these uses include wire spools, cash-and-carry utility lumber, specialized containers, decorative paneling, and mine timbers.

Because of the abundance of conifers and conifer residues, prospects for utilization of aspen for pulp, particleboard, or fiberboard in the Rocky Mountains are not immediate. At present, there are no fiberboard or particleboard plants within the area and only one pulp-mill in the Southwest--inaccessible to most of the aspen resource.

^{1/} Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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^{3/} This is a summary of some of the information presented in a report in-press by this author entitled, "Guidelines for Utilization and Marketing Rocky Mountain Aspen" to be published by the USDA Forest Service Rocky Mountain Station.

Because of aspen's small size and high defect incidence in the core, conventional veneer production has very low potential. There are no plywood mills in the area, although there is one match splint factory that produces veneer for that purpose.

Fuel demand in the Rocky Mountains is quite low as there are few industrial users when compared with other areas in the U.S. Hence, fuel wood has a low potential except within the industry and for fireplace wood.

All indications are that there is good demand for wood residues for animal and poultry bedding. However, most of this demand is east of the Continental Divide while the aspen is west.

The use of aspen for excelsior in the West has been continuing for many years and probably has utilized more aspen sawtimber than any other use. The excelsior industry has been subject to many oscillations in demand. However, with shortages in plastics, it might be anticipated that demand for excelsior will increase.

There are certainly other market niches for aspen--paneling, shingles, stakes, tongue depressors, novelty items, wood flour, and so on--that will continue to use small amounts of raw material and manufacturing residues. These uses should be developed further.

Trends And Prospects For Use In Fiber Products¹

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ABSTRACT.—About 85 percent of the operating pulpmills in the Lake States use some aspen. In recent years the aspen percentage has varied between 45 and 50 percent of all pulpwood use. Pollution abatement orders may result in some changes in pulpwood use. Aspen has good credentials for use in fiber products. It is light colored, making its use for groundwood pulp attractive. It is readily pulped by any of the commercial processes, and is a raw material most often used in process developments because it is easily pulped. Aspen fiber morphology is excellent. The length-to-diameter ratio and the thin-to-medium-thick walled fibers are particularly suited to enhancing fine paper structure. Its low density is attractive to fiberboard production. The relative low yield per unit cost for aspen probably restricts potential expanded use.

Within the past 25 years we have seen a tremendous increase in the use of all types of hardwoods for fiber product manufacture. While a cost advantage may have been the first and perhaps still is the foremost incentive, certain quality gains were realized so that today hardwood fibers are essential to the satisfactory performance of many fiber products.

In the northern United States aspen has since the early 1940's been the major factor in the remarkable growth in hardwood consumption for pulping.

Recent statistics on aspen use in the Lake States illustrate its importance and availability. Nearly 85 percent of the pulpmills operating in this area use some aspen, and this use comprises some 45 to 50 percent of all the pulpwood consumed (table 1). This speaks well for aspen's use in fiber products since it is estimated to make up about 30 percent of the timber volume.

We are all aware that pressures for pollution abatement are causing wide-scale reevaluations by the fiber products industry. It is too early to attempt to analyze what this may mean for aspen.

Aspen and poplar species in general have been the subject of extensive research throughout the world (Brown, Seager, and Weiner 1957; Roth and Weiner 1964, Weiner and Roth 1970). Much of this research is related to growth, but the general ease in processing and the quality of the resulting fibers and fiber products have made these species somewhat of a standard in the control and evaluation of new products and processes.

WOOD PREPARATION

When aspen first entered pulpwood markets, most was sap-peeled in the woods before shipment. In recent years, preparation has changed dramatically and many pulpmills now practice "hot logging," debark at the mill, and store a limited time. Perhaps the most important factors in the change were the general rise in storage costs and a significant brightness loss resulting from extended storage of peeled logs. Prolonged storage is still practiced when the wood is used in the sulfite or bisulfite process for alleviating potential pitch problems. Other factors were the limited labor market and the lack of accepted portable debarkers. Today we find year-round harvesting and preparation operations for aspen with debarking both in the woods and at the mill.

For debarking at the mill site, mechanical and

¹ Paper was presented at a previous aspen symposium in the Lake States. It was referred to in the Rocky Mountain symposium and is reprinted here because of its particular relevance to the subject.

² Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Table. 1 — *Lake States pulpwood production*
(In thousands of rough cords)

Kind of pulpwood	1965	1967	1968	1969	1970
Hardwood					
Aspen (roundwood)	1,780	1,976	1,753	1,963	1,966
Other miscellaneous (roundwood)	444	539	449	555	658
Residues	8	195	219	259	302
Softwood					
Roundwood	1,268	1,235	1,091	1,139	1,313
Residues	31	20	39	27	46
Total production	3,531	3,965	3,551	3,943	4,285
	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>
Aspen	50	50	50	50	46

drum debarkers or combinations thereof are used. Wood cut and delivered during the sap peeling season cleans up quite satisfactorily in one pass, but multiple passes are required for tight-bark seasons. Some operators have found that series installation of debarkers has advantages over recycle systems.

Portable debarking equipment has been added to some woods operations and concentration yards away from the mill site have been developed. New forestry and harvesting practices for optimum management of our wood resource will no doubt force a growth in these types of systems (Benson and Peckham 1968).

Whole tree utilization has potential in the fiber products field. Bark-chip separation techniques will be required for some products. Various methods are under investigation and it is expected that alternatives will be available for both the processor and the user of the wood.

Aspen, when improperly debarked, has been known to cause some operating problems. Perhaps the most troublesome of these is the filling of paper machine wire caused by deposits of stone cells from the inner bark on the wire, a problem similar to the filling caused by resinous woods.

PULPING BY COMMERCIAL METHODS

Pulping, the separation of wood into fibrous elements, is accomplished by mechanical means, by

chemical removal of the lignin and incrustants, or by combinations of these two procedures. In each case, the pulp characteristics needed for a particular wood fiber product along with economic considerations determine the choice of the process — groundwood, chemimechanical, semichemical, sulfite, or kraft.

Aspen is readily pulped by any of these commercial processes (Brunson 1964). In fact, it is the wood most often used in development work because of the general feeling that if you cannot pulp aspen with the technique under development, you most likely do not have a viable plan or program. Processing conditions are not uniform from mill to mill for any of the processes, but can be controlled at an optimum for each pulp and fiber product situation. For the optimum, a wood specification such as percentage of rot, size, brightness, or other wood factor could be included. Table 2 gives estimated pulp yields of different species for each of the commercial processes.

The data demonstrates quite clearly the yield advantages of the higher density woods and the importance of including cost in the calculations so that yield per unit cost can be the comparable unit.

Groundwood

Two procedures are available for producing groundwood pulps, which in 1970 accounted for almost 4½ million tons of production in the United States, of which aspen approached 10 percent.

Table 2.—*Estimated yields of pulp for various wood species*

Species	Ovendry wood	Pulping processes					
		Groundwood	Chemimechanical	Semichemical		Sulfite	Kraft
				80 percent yield	60 percent yield		
	Lbs./cord	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton	Cords/ton
Aspen	1,825	1.08	1.15	1.31	1.62	1.88	1.97
Black spruce	1,990	.99	1.06	--	--	1.90	1.96
Hemlock	1,990	.99	1.06	--	--	1.95	2.05
Southern pine	2,405	.83	--	--	--	--	1.66
Birch	2,490	--	.85	.96	.83	1.46	1.39
Beech	2,905	--	.76	1.18	1.02	1.54	1.41

The conventional stone grinding process involves holding logs under specified pressures against a rotating grinding wheel of a designated grit size, structure, and surface pattern. Bundles of fibers, individual fibers, and parts of fibers are separated from the log and further ground to form a pulp of desired fiber size distribution and strength. Low-density woods such as aspen are best suited to this process for the production of optimum groundwood quality (Hytinen, Martin, and Keller 1960; Perry and Canty 1971).

In recent years, a second method for groundwood pulp manufacture has come into significant use. This is the refiner groundwood process which developed primarily as a result of the availability of chips from sawmills or other residue sources (Allan, Skeet, and Forgacs 1968). In this process, the wood chips are reduced to fiber and fiber fragments by refining in a series of attrition mills, commonly called disc mills. The resulting pulps are known by a variety of names — refiner groundwood, disc woodpulp, super groundwood (Richardson and Le Mahieu 1965), and others.

Although the two groundwood pulps are used in similar paper grades, the refiner pulp is usually superior in both tear and bonding strengths, has more long fibers, is poorer by varying degrees in opacity and brightness factors, and usually requires the papermaker to adapt his machine to a change in runnability.

Aspen groundwoods can produce the paper with highest printing quality of any groundwoods and their somewhat lower strength does not materially affect runnability factors on either the paper machine or the printing press.

Chemimechanical

Chemimechanical pulps are the result of a very mild chemical action to delignify and soften wood chips for subsequent refining in a disc mill (Leask 1968) at yield ranges of 80 to 95 percent. Steam-treated pulps characterized by those from the Masonite and Asplund process are included in this category.

The chemical and steam treatments or combinations of the two permit more effective fiberizing and also allow the use of the higher density hardwoods. Certain physical properties are enhanced. These pulps have some use for fine paper but are most used in coarse papers and in many kinds of fiberboard (Fahey and Steinmetz 1971). In this latter category, the low density of aspen is an advantageous factor, especially for the low and medium density fiberboard field. Growth rate in the fiberboard market approaches 10 percent per year.

Semichemical

Semichemical pulps (Vamos, Lengyel, and Mero 1964; Van Eychen 1968) differ from the chemimechanical types by yielding less — 60 to 80 percent. The chemical treatment is somewhat more severe and the subsequent fiberizing requires less power. Some 3½ million tons of semichemical pulps were produced in the United States in 1970 using all types of hardwoods but with negligible aspen use.

Aspen pulpwood, however, is suitable for this process and the resulting pulps are usable in both fine and coarse paper. Almost all of the semichemical pulp tonnage goes into coarse paper grades where the yield per unit cost advantage of the higher density hard-

woods limits aspen use. In the fine papers, kraft and sulfite pulps are preferred.

Sulfite and Kraft

These processes together with bleaching delignify pulps completely and make them suitable for fine paper. The aspen pulp fibers resulting from these processes have special quality characteristics that make them particularly suitable for fine paper structure. They have thin- to medium-thick walls and a length to diameter ratio in excess of 30. While vessel elements are numerous, their diameter is well below that which results in the well-known and disastrous fiber pick problem associated with printing papers containing oak pulp. Thus the fine papermakers, especially those using sulfite pulps, have good reasons to want aspen in their wood procurement plan.

OTHER PULPING METHODS

New pulping methods arise from laboratory and pilot investigations but usually fail to replace those just presented for economic or pulp quality reasons, or both.

Solvent pulping is routinely offered for consideration as a commercial process. A goodly number of solvents together with a hydrolysis reaction will remove lignin from wood, but the processes remain unattractive despite steady promotion in isolated cases.

In general, the commercial potential for new pulping methods must be judged on the basis of the quality obtainable in relation to present methods and the pollution abatement technology economically available for these processes.

It is highly probable that if and when a new pulping process is put through the paces of pilot planting and commercial evaluation, aspen pulpwood would be one of the first wood species to be used.

SUMMARY AND CONCLUSIONS

In summary then, we know that aspen is available and is readily pulped by any of the commercial processes now in use. This fact strongly suggests that if and when pulping processes are changed, aspen will still be a readily usable source of pulp.

The bulk of the aspen pulpwood produced in the Lake States is used in the groundwood, chemimechanical, and sulfite processes. Aspen pulp in these processes provides the pulp quality needed at an economic advantage over other species.

The groundwood pulps are used mostly in printing paper grades. Here aspen provides highest printing quality and opacity without sacrificing runnability on either the paper machine or printing presses. The publication paper segment of the industry recently suffered production cuts but should recover with the general business upturn expected. Small quantities of aspen groundwood are used in tissue at some expense in quality but with economic advantage. This must never be considered a significant outlet.

Chemimechanical pulps are used principally in fiberboards and to a very limited degree in fine papers. In fiberboard, the low density of aspen is an important factor for the low and medium density products. The fiberboard market is expanding at a 5 to 10 percent rate per year.

Aspen is used in sulfite pulpmills for the production of pulps for fine paper grades. Sulfite pulping, however, is in decline and such mills are being shut down. Modifications of sulfite pulping with recovery systems are operating and planned for the Lake States. The real future of this outlet, however, is still cloudy and unpredictable.

Therefore aspen must look to groundwood and chemimechanical pulping for its future. Its advantageous fiber morphology, as shown on table 3, makes it a desirable wood fiber, but its low density is a serious economic disadvantage that limits expansion to other processes and paper grades.

LITERATURE CITED

- Allan, R. S., C. W. Skeet, and O. L. Forgacs. 1968. Refiner groundwood from deciduous species. *Pulp & Pap. Mag. Can.* 69(18): 74-80 (T351-7).
- Benson, M. K., and J. R. Peckham. 1968. Preliminary observations on a bark and wood-chip separation procedure for aspen. *Genet. Inst. Pap. Chem. Physiol.* Note 2.
- Brown, C. L., G. Seager, and J. Weiner. 1957. Constitution and pulping of aspen and poplar woods. *Inst. Pap. Chem. Bibliogr. Ser.* 184.
- Brunson, F. H. 1964. Suitability of various hardwoods for pulping. *South. Pulp & Pap. Manuf.* 27(11): 82, 84-6, 88, 90, 92.

Table 3. — *Physical and chemical characteristics of five pulpwoods*¹

Species	Morphology							Cellulose	Lignin	Hemi-cellulose	Density
	Fiber length	Vessel length	Fiber width	Wall thickness	Fiber volume	Vessel volume	Ray volume				
	Mm.	Mm.	Microns	Microns	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Aspen	0.95	0.55	18-40	2.2	53	33	14	53	16	31	22
Birch	1.20	.95	20-36	2.8	66	21	11	41	19	40	35
Maple	.70	.35	16-30	2.8	61	21	18	41	24	35	35
Spruce	3.20	--	28-40	2.9	93	--	6	44	28	28	24
Southern pine	3.50	--	35-45	3.8	90	--	10	41	29	30	30

1/ Sources of data: Forest Products Laboratory, Rydholm (1965), Joint Textbook Committee of The Paper Industry (1969), Marton and Alexander (1964).

- Fahey, D. J., and P. E. Steinmetz. 1971. Effect of manufacturing variables on stability and strength of wet-formed hardboards. USDA For. Serv. Res. Pap. FPL-142, 9 p. For. Prod. Lab., Madison, Wis.
- Hytinen, A., J. S. Martin, and E. L. Keller. 1960. Pulping and papermaking experiments on quaking aspen from Colorado. For. Prod. Lab. Rep. 2180, 14 p.
- Joint Textbook Committee of The Paper Industry. 1969. Pulp and paper manufacture. I. The pulping of wood. Ed. 2, p. 1-72. New York: McGraw-Hill Book Company.
- Leask, R. A. 1968. Chemimechanical pulps from hardwoods. Tappi 51(12): 117-20A.
- Marton, R., and S. D. Alexander. 1964. Properties of fiber fractions from chemical and mechanical pulps, 3. Comparison of poplar and spruce pulps. Tappi 47(11): 704-10.
- Perry, F. G., and C. Canty. 1971. Improved economics and better quality for mechanical pulp. Pap. Trade J.

155(30): 30-33.

- Richardson, C. A., and J. R. Le Mahieu. 1965. Superground-wood from aspen. Tappi 48(6): 344-346.
- Roth, L., and J. Weiner. 1964. Constitution and pulping of aspen and poplar woods. Inst. Pap. Chem., Bibliogr. Ser. 184, Suppl. I.
- Rydholm, S. A. 1965. Pulping processes p. 42-88. New York: Interscience Publishers.
- Vamos, G., P. Lengyel, and T. Mero. 1964. Utilization of some hardwood semichemical pulps for the production of corrugating paper. Svensk. Papperstid. 67(13): 529-35.
- Van Eychen, H. K. 1968. Canadian International Paper Corrugating Medium Mill on stream at Matane. Pulp & Pap. Mag. Can. 69(2): 24-9.
- Weiner, J., and L. Roth. 1970. Constitution and pulping of aspen and poplar woods. Inst. Pap. Chem., Bibliogr. Ser. 194, Suppl. II.

Rocky Mountain Aspen For Pulp: Some Market Opportunities And Limitations¹

Thomas J. Loring²/

Abstract.--Aspen compares favorably with most hardwood species preferred for pulping. Relative abundance and pulping ease contribute to aspen providing more than half of the Lake States pulpwood. Few pulp mills in the Rocky Mountains can now use aspen, and distances limit aspen shipment to mills elsewhere. However, projected rising fiber demand and the need for aspen management in the Rockies should help promote viable markets for pulp and fiber from local aspen.

While it is considered a short-fibered, relatively low density species, aspen compares favorably with most of the hardwood species preferred for pulping. Currently, in the Lake States, aspen is reported as providing more than half of the total pulpwood cut -- amounting to something over 2 million cords of aspen per year.

Undoubtedly, the abundance of aspen fairly close to established pulp mills is a factor in its increasing use in certain areas. Abundance, plus the fact that aspen is readily digested by most pulping processes (with predictable yields of 52% for sulfite, 54% for kraft and produces a pulp suitable for corrugated medium or easily refined for use in book and specialty papers, also are positive opportunities in marketing of aspen for pulping.

A major limitation on marketing aspen for pulp in the Rocky Mountain area at this time is the limited number of pulp mills in the area and the great distances to established mills elsewhere. Almost certainly, other limitations include: financial constraints on modifying or expanding existing pulp mills or constructing new ones, uncertainly as to actual assured volumes of aspen available over the long term, and the fact that rather than producing marketable by-products such as tall oil, aspen pulping tends to produce broken and short fibers which can be a disposal problem.

¹/ Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976

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With the Nation's rising demands for fiber products and some definite moves towards serious management of aspen stands in the Rockies, it appears inevitable that aspen pulp for a variety of markets will be produced eventually in the Rockies. Certainly, aspen can provide considerable volumes of furnish for molded fiber items such as egg cartons, extenders for plastic or composition products, corrugated, medium and even structural particle board -- all of these from relatively unrefined pulp which conceivably could be derived from whole-tree chips produced in the woods.

With further refining, bleaching, etc., aspen pulp can supply all or a major part of the furnish for quality printing and specialty papers. Some recent work even appears to suggest that aspen pulp could be a major source of livestock feed for sheep and cattle.

Background Notes on Pulping Aspen

Relative Yields Percent

Process	Aspen	Ponderosa Pine
Kraft (Sulfate)	54	48
Sulfite	52	45
Groundwood	95	95

Relative Specific Gravity

Aspen:	Green	Air Dry
Quaking	0.35	0.38
Big Tooth	.36	.39

Pine

Lodgepole	.38	.41
Ponderosa	.38	.40

Average Fiber Length mm

Aspen

Quaking	1.20
Big Tooth	1.20

Pine

Lodgepole	3.50
Ponderosa	3.60

References

Forest Service, USDA

1974. Wood Handbook: Wood as an engineering material USDA Agric. Handbook 72.

1964. Pulp yields for various processes and wood species. U.S. For. Serv. Res. Note FPL - 031. For. Prod.

1975. Quaking aspen: Silvics and management in the Lake States. USDA Agric. Handbook 386.

Hanson, James P. and Mies, W. E.

1976. Southwest Forest Industries completes a major expansion. Pulp and Paper 60(9);48

Panel IV.
Research Advances In Aspen Utilization

Moderator: Frederick F. Wangaard

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Some Properties And Characteristics Of Aspen That Affect Utilization In The Rocky Mountains¹

Eugene M. Wengert^{2/}

Abstract.--There are large volumes of aspen (Populus tremuloides Michx.) in the Rocky Mountain West. The utilization of this aspen is necessary for the management of the aspen type, yet utilization has been minimal. In this report, the aspen tree, the wood's properties, and the wood's processing characteristics are examined, in order to provide up-to-date information and to thereby assist in utilization of Rocky Mountain aspen.

THE ASPEN TREE

The typical Rocky Mountain aspen sawtimber tree is, at maturity, 80 to 100 years old, 60 to 80 feet high, and 11.0 inches d.b.h. or larger (Baker 1925). (There are trees over 200 years old, over 100 feet high, and over 20 inches d.b.h.) Other characteristics of the mature tree are that it has frequently begun to decay in the center (usually caused by Phellinus tremulae (Bond.) Bond. et Buris with some evidence of the false timber fungus conks (Davidson et. al. 1959) on the trunk, has a crooked or sweepy stem, and has many knots, especially in the central portion of the stem. A sample of merchantable trees from Southwest Colorado has shown that the average log taper is 0.114 inch per foot of length, approximately

25 percent of the gross scaled footage is defective (about one-half is due to crook and sweep). Bark volume averages about 17 percent of the gross log volume which is higher than the value of 12% for Minnesota aspen. The average double thickness (B) was related to dib at the large end of tree length logs by $B = -(0.086) + (.0854) (\text{dib})$. Bark thickness at any location along the bole was related to dib and dob at that location (Peterson 1961).

$$B = -(0.3168) + (.1046)(\text{dob})$$

$$\text{and } B = -(0.3538) + (.1168)(\text{dib})$$

where B and the diameters are in inches.

Gross volume relationships for aspen trees have also been determined (Peterson 1961) for diameters in inches and heights in feet:

$$V = \frac{[(\text{d.b.h.}, i.b.^2 + 36) 1.1214 (\text{ht. to 6-inch top, dib.} - 8.150.9427)]}{96.3829} + 9$$

where

V = volume, bd. ft. Scribner, to a 6-inch top

$$\text{and also } V = \frac{[(\text{d.b.h.}, i.b. - 4) .0827 + B (\text{total ht.} - 4.5) .4045]}{2.9655} + .3$$

where

$$V = \text{volume, cu. ft., to 4-inch top (d.i.b.)}$$

$$B = .6593 \log_{10} (\text{total ht.} - 4.5)$$

$$\text{d.b.h.}, i.b. = 0.8954 (\text{d.b.h.}, o.b.) + 0.3168$$

^{1/} Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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This latter equation has been successfully applied to aspen from Utah, Colorado, and New Mexico by the author.

PROPERTIES

Structure

Since aspen belongs to the hardwood, or broad-leafed class of trees, the wood has numerous pores (vessels) scattered among the fibers. The pores are very small, however, being barely visible with the unaided eye. The pores are fairly uniform in size throughout the annual ring, although they become slightly smaller toward the end of the growing season. As a result, the annual rings are distinctly but not conspicuously defined. The rays are extremely low and narrow, being only one cell wide. The fibers, the most abundant cell, are much shorter than softwood fibers, 3-4 times shorter. The result of these characteristics is that aspen is very uniform in texture, structure, and appearance.

Aspen has many loose knots that may break or fall out during processing. Aspen also has tension wood scattered throughout the stem which causes some processing problems (Kennedy 1968).

Color, Odor, and Texture

Usually the wood of aspen, both heartwood^{3/} and sapwood, is quite white. However, there are discolorations around knots and in the center portions of the tree, often attributed to bacterial wetwood and to the early stages of heart rot.

Aspen wood is practically tasteless and odorless when dry. When wet, aspen wood, especially bacterial wetwood, has a distinctive and sometimes slightly unpleasant odor. Aspen is a soft, virtually splinterless wood.

Specific Gravity and Weight

When green, aspen weighs 43 pounds per cubic foot on the average. Wetwood can increase this to 50 pounds or more per cubic foot. At 12 percent moisture content, aspen weighs 27 pounds per cubic foot.

^{3/} It is the author's general observation that Rocky Mountain aspen contains considerably more heartwood than Lake States aspen.

The weight of aspen, 1-1/8-inches thick at 20 percent moisture content is approximately 2774 pounds per thousand board feet. Aspen lumber, surfaced to 25/32-inch, would weigh approximately 1760 pounds per thousand board feet at 12 percent moisture content (Johnson 1947).

One cord of aspen pulpwood with the bark weighs 4075 pounds (approximately) green. A cord contains approximately 607 pounds of green bark at 95 percent moisture content.

A specific gravity of 0.38 (green volume, ovendry weight) with a range of at least ± 0.08 is the most accurate for Rocky Mountain aspen based on the author's unpublished data at the Rocky Mountain Forest and Range Experiment Station. This is the same as for Lake States' (Erickson 1972) and Canadian aspen (Kennedy 1965).

Due to the action of bacteria in bacterial wetwood, the specific gravity of wetwood is found to be 0.03 to 0.04 lower than for normal aspen wood (Haygreen and Wang 1966 and Kennedy 1974). Tension wood will increase specific gravity 0.02 to 0.06 units (Kennedy 1968).

Aspen bark specific gravity is approximately 0.45 with a range of 0.38 to 0.57.

Green Moisture Content

The moisture content of the standing tree is quite variable, depending primarily on the season and whether wetwood is present. Normal sapwood values range from 65 percent or higher in the summer to 90 to 110 percent in the winter; wetwood values can run as high as 160 percent (Bois 1974 and Yerkes 1967). Heartwood values are approximately 10 to 20 per. m.c. lower than sapwood.

Shrinkage

Aspen has a fairly low shrinkage--3.5 percent (green to ovendry radial), 6.7 percent tangential, and 11.5 percent volumetric (FPL 1974). The large tangential to radial shrinkage ratio means that aspen will be subject to cupping and diamonding when moisture content changes occur in drying and in use.

Longitudinal shrinkage is usually ignored for most species, but for aspen, which has an abnormal amount of tension wood, longitudinal shrinkage can be significant--0.16 to 0.72 percent, green to ovendry (Kennedy 1968). This longitudinal shrinkage means that aspen will be subject to bowing, crooking, and veneer buckling when moisture content changes occur in drying and in use.

Strength and Mechanical Properties

Values of strength are given in Table 1, design values in Table 2.

Nailholding Power

The average holding power of a sevenpenny, cement-coated nail driven 1-1/4 inches into the side grain of dry or green aspen is about 194 pounds. The same nail driven into green aspen is only about 20 pounds after the wood has thoroughly dried (Johnson 1947).

The nailholding power of aspen is comparatively low. To compensate for this, more or larger diameter nails with larger heads can be used to obtain higher power. Fortunately, aspen has very little tendency to split when nailed and this makes up for some of its low nailholding power.

Gluability

Laboratory tests and experience have shown that aspen is one of the easiest species of wood to glue. However, aspen is quite absorptive, so rapid assembly is required. With some adhesives, water must be added to prevent premature drying of the adhesive.

Finishing

Aspen is one of the best hardwoods for paint holding ability (Zasada 1947). Of course, knots must be carefully primed. Aspen also takes stain very well, but uneven adsorption causes a "blotchy" appearance. A wash coat or sealer application prior to staining will alleviate this problem. Aspen also accepts ink very well.

PROCESSING

Machining and Related Properties

Machining is a broad term that includes sawing, planing, shaping, sanding, boring, and the like. Aspen machines easily in that power consumption is low and tools are not dulled rapidly. However, it is difficult to obtain a good surface on aspen, unless special care is taken. Aspen's fibers sever less cleanly than most other woods, due in part to tension wood, thereby leaving a fine fuzz on the surface. Excellent turnings, borings, and sanded surfaces can be obtained if the following procedures are followed where appropriate (Davis 1947 and 1962, Stewart 1973, Wengert 1973)

- (1) Moisture content, 6 percent or less.
- (2) Knife angle, 25° to 30°.
- (3) Feed rate or lathe speed, slow (22 cuts per inch in planing).
- (4) Cutter head speeds, high--peripheral speed above 5000 fpm.
- (5) Revolve work against the knife direction in lathe or feed lumber so cutter head moves with the grain in planing.
- (6) Use a shallow, 1/32-inch, final cutting depth.
- (7) Plane lumber across the grain.
- (8) Boring should be done using a slow feed speed.
- (9) Very fine sanding increases fuzz.

Based on only a small number of tests, it appears that wetwood aspen machines more poorly than normal aspen.

The fuzziness that is common to aspen can be removed by proper sanding procedures, by using special abrasives, by using an antifuzz sealer, or by using a wash coat before final sanding.

In short, with extra care aspen can be machined to give excellent surfaces.

DECAY RESISTANCE

Both the heartwood and sapwood of aspen are low in natural decay resistance. Untreated aspen posts or lumber in contact with the soil may last only two or three years. Due to the low, permeability of aspen wetwood and heartwood, some difficulty is experienced in getting aspen to accept a uniform preservative treatment (Cooper 1976). Usually the small diameter logs treat best. With a suitable treatment, aspen can give very good service in moist locations (Kaufert 1948).

Table 1.--Mechanical properties of aspen (*P. tremuloides*)

	Specific gravity		Moisture content at test	Static bending						
	Green vol.	Percent		Stress at P.L. (psi)	Modulus of rupt. (psi)	Modulus of elas. (psi)	Work (in. lb./cu. in.)			
			To P.L.				To max. load	Total		
Normal SG	0.37	green	2900	5500	1,310,000	0.37	6.9	20.2		
Low SG	.35	green	--	5100	860,000	--	6.4	--		
Normal SG	.37	12	5200	9800	1,630,000	.99	10.3	21.0		
Low SG	1.37	12	--	8400	1,180,000	--	7.6	--		
Wetwood	2.329 3.357	green	2666	4973	612,000	--	--	--		
	Compression parallel to grain		Compression perpendicular to grain	Hardness (lb.)	Shear parallel to grain	Cleavage	Tension perpen. (5/8-in. sq. sample)	Toughness		
	Stress at P.L. (psi)	Max. crushing stress (psi)							Modulus of elas. (psi)	Stress at P.L. (psi)
			Side	End	(lb./in.)	(psi)	(in.-lbs.)			
Normal SG, green	1510	2350	1,250,000	200	320	340	720	440	180	4165
Low SG, green	--	2140	2,140,000	180	300	--	660	230	--	4115
Normal SG, 12%	3280	5270	5,270,000	510	480	630	980	610	260	4115
Low SG, 12%	--	4250	--	370	350	--	850	260	--	--
Wetwood, green	1428	1878	525,000	--	--	--	--	--	--	--

¹Specific gravity 0.38 at 12% moisture content.²Comp. II³Bending.⁴Specific gravity = 0.39

Sources: Low specific gravity -- FPL 1974; Normal SG--Kennedy 1965; wetwood--Haygreen and Wong 1966.

Table 2.--Recommended design values (PSI)¹ for WMPA graded lumber (WWPA 1974)

	Extreme fiber stress in bending "F _b "		Tension parallel to grain "F _t "	Horizontal shear "F _v "	Modulus of elasticity "E"	
	Single	Repetitive			Perpendicular "F _c " ₁	Parallel "F _c "
<u>Light framing and studs - 2" to 4" thick, 2" to 4" wide</u>						
Construction ²	650	750	400	60	185	625
Standard ²	375	425	225	60	185	500
Utility ²	175	200	100	60	185	325
Studs	500	575	300	60	185	325
<u>Light framing - 2" and less in thickness, 2" wide</u>						
Construction	600	700	325	60	185	625
Standard	275	325	150	60	185	500
Utility	75	100	50	60	185	200
<u>Light framing - 3" and less in thickness, 3" wide</u>						
Construction	550	625	300	60	185	625
Standard	350	400	200	60	185	500
Utility	100	125	50	60	185	250
<u>Structural light framing and appearance - 2" to 4" thick, 2" to 4" wide</u>						
Select structural	1300	1500	775	60	185	850
No. 1/appearance	1100	1300	650	60	185	675/825
No. 2	925	1050	525	60	185	550
No. 3	500	575	300	60	185	325
<u>Structural joists and planks and appearance - 2" to 4" thick, 6" and wider</u>						
Select structural	1150	1300	750	60	185	750
No. 1/appearance	950	1100	650	60	185	675/825
No. 2	775	900	525	60	185	575
No. 3	450	525	300	60	185	375
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¹These design values apply to lumber when used at a maximum moisture content of 19% such as in most covered structures.

²F_b, F_t and F_c recommended design values apply only to 4" widths of these grades.

LITERATURE CITED

- Baker, F. S.
1925. Aspen in the central rocky mountain region. USDA Bull. 1291. Wash., D.C. 46 p.
- Bois, P. J.
1974. Aspen--the cinderella species. Wood and Wood Prod. 79:25-27,80.
- Cooper, P. A.
1976. Pressure preservative treatment of poplar lumber. For. Prod. J. 26(7):28-31.
- Davidson, R. W., T. E. Hinds, and F. G. Hawksworth.
1959. Decay of aspen in Colorado. USDA Forest Serv. Rocky Mtn. Stn. Pap. 45, 14 p.
- Davis, E. M.
1947. Machining and related properties of aspen. USDA Forest Serv. Lake States Aspen Rep. 8, 8 p.
1962. Machining and related characteristics of U.S. hardwoods. USDA Tech. Bull. 1267, 68 p.
- Erickson, J. R.
1972. The moisture content and specific gravity of the bark and wood of northern pulpwood species. USDA Forest Serv. Res. Note NC-141, 3 p.
- Forest Products Laboratory.
1974. Wood Handbook: Wood as an engineering material. USDA Agric. Handb. 72, rev. Wash. D.C. 426 p.
- Haygreen, J. G., and S. S. Wang.
1966. Some mechanical properties of aspen wetwood. Forest Prod. J. 16(9):118-119.
- Johnson, R. P. A.
1947. Mechanical properties of aspen. USDA Forest Serv. Lake States Aspen Rep. 7, 16 p.
- Kaufert, F. H.
1948. Preservative treatment of aspen. USDA Forest Serv. Lake States Aspen Rep. 19, 19 p.
- Kennedy, R. W.
1965. Strength and related properties of woods grown in Canada. Dep. Forestry and Rural Dev. Publ. 1104.
1968. Anatomy and fundamental wood properties of poplar. In Growth and Utilization of Pop. in Canada, Chap. IX, pp. 149-168. Dep. Forestry and Rural Dev. Publ. 1205, Ottawa
1974. Properties of poplar that affect utilization. In Pop. Utilization Symp., pp. 51-64, Western Forest Prod. Lab. Inf. Rep. VP-X-127, Vancouver.
- MacKay, J. F. G.
1974. High-temperature kiln-drying of northern aspen 2- by 4-inch light-framing lumber. Forest Prod. J. 24(10):32-35.
- Peterson, G.
1961. Volume tables for aspen in Colorado. USDA Forest Serv. Res. Note RM-63, 4 p.
- Stewart, H. A.
1973. Cross-grain knife planing improves surface quality and utilization of aspen. USDA Forest Serv. Res. Note NC-127, 4 p.
- Wengert, E. M.
1973. Aspen workshop held by Wood Seasoning Assn. South. Lumberman 227(2524):190-191.
- Western Wood Products Association
c.1974. Recommend design values, aspen and red alder. WWPA, Portland 1 p.
- Yerkes, V. P.
1967. Effect of seasonal stem moisture variation and log storage on weight of Black Hills ponderosa pine. USDA Forest Serv. Res. Note RM-96, 8 p.
- Zasada, Z. A.
1947. Aspen properties and uses. USDA Forest Serv. Lake States Aspen Rep. 1, 9 p.

Research Advances In Aspen Utilization For Pulp¹

Eugene M. Wengert^{2/}

SUMMARY

Aspen (Populus tremuloides Michx.) is widely used for pulp in the Lake States and in Canada. Several recent reviews of aspen for pulp and research needs have been compiled (Auchter 1972, Keays et. al. 1974, and Neilson 1975. Since Auchter's paper provides a concise review of current pulping technology that should be applicable to Rocky Mountain aspen, it is reprinted here in full.) Lack of basic research information does not appear to be a major barrier to the use of Rocky Mountain aspen for pulp. However, if aspen is to be blended with the indigenous conifers, operational parameters will have

^{1/} Discussion presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

^{2/} Extension Specialist, Forestry. Virginia Polytechnic Institute and State University, Blacksburg, VA 24061. (Formerly with USDA Forest Service, Forest Products Laboratory)

to be established to achieve suitable pulp quality. Likewise, various tree diseases common in Rocky Mountain Aspen will affect pulp yield and pulp quality to a small extent. Disease losses would contribute primarily to decreased yield per unit cost, affecting the merchantability of some stands. In short, any lack of use of aspen for pulp in the Rocky Mountains will stem basically from marketing and/or economic considerations.

LITERATURE CITED

- Auchter, Richard J.
1972. Trends and prospects for use in fiber products. In Aspen: Symposium Proceedings. pp. 40-45. USDA For. Serv. Gen. Tech. Rpt. NC-1.
- Keays, J. L. et. al.
1974. Present and future uses of Canadian poplars in fiber and wood products. Canad. For. Serv. Info. Rpt. VP-X-120. 49 p.
- Nelson, R. W.
1975. Poplar utilization: a problem analysis. Canad. For. Serv. Info. Rpt. VP-X-149. 65 p.

Lumber Yield From Rocky Mountain Aspen¹

Eugene M. Wengert^{2/}

SUMMARY

Aspen (*Populus tremuloides* Michx.) is an underutilized species in the Rocky Mountain West. Colorado has more aspen sawtimber than any other state, but its annual harvest of aspen sawtimber for use in sawn products is less than 5 million board feet. Although many factors contribute to this underutilization, one important reason is the unfamiliarity with the species and the product potential of standing timber or logs. The purpose of this study was to develop and evaluate a method of determining this potential for board or mine timbers and dimension lumber.

In this study aspen trees from northern New Mexico and eastern Utah were graded, based

^{1/} Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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on d.b.h. and on the presence and frequency of conks and scars, were then felled and sawn into 8-foot logs. The logs were graded on the basis of decay, sweep (or crook), and scaling diameter. The logs were then sawn into boards, dimension lumber and mine timbers. Sawn product recoveries, both volumes and dollar values, were related to tree and log grades. Both grading systems were able to separate trees and logs into different recovery levels--volume and dollar value.

The log grades performed well in New Mexico for separating the logs into definite value classes (\$ per 100 cu. ft.), recovery classes (both log recovery factor (LRF) and percent of log volume converted to lumber), and lumber grade recovery (yield of #2 and #3 Common and better). In Utah, the log grades were less effective in predicting LRF and volume recovery. However, they correlated better with lumber grade recovery (yield of #2 Dimension and Better and mine posts) and dollar value.

The full results of this study will be published in a technical report, to be issued by the Rocky Mountain Forest and Range Experiment Station.

Processing Low Quality Trees By The SHOLO Approach¹

Vern P. Yerkes^{2/}

Abstract.--(SHOrt LOG) processing can alleviate some critical problems of processing aspen into a marketable product. High quality bolts (<8') are bucked from each log to the length required by the target product. Only quality blocks are then transported to and handled at the processing mill. This system has proven effective in pallet part production in the eastern U. S. Successful implementation of the SHOLO system requires careful analysis of seven key planning steps. Identification of the target products is essential so all primary processing is directed to these products without need for a secondary processing system.

The Colorado State Forest Products Bulletin of July 1976^{3/} contains a statement which graphically portrays some critical problems of processing Aspen into useful consumer products.

"...merchantable volume is significantly limited by a combination of characteristics which also results in higher processing costs (1) a high proportion of crooked small diameter trees and (2) a high incidence of decay occurring in overmature stands."

The impact of these characteristics can be markedly reduced through high-speed processing of short logs (<8') directly into a marketable product without first processing long logs then remanufacturing lumber into the product.

The suggested approach is to buck low quality crooked stems into short blocks cut

to the dimension (length) needed in the target product. All crook possible is bucked out producing short straight blocks. Also any defect not acceptable in the target product can be bucked out. This would mean that only the higher quality sections of the tree would be processed into the product. All other pieces would be relegated to the chipper (or other lower valued product) in the round log form. The operator incurs no unnecessary processing costs by handling those sections of the tree that were unsuited for his product.

This approach to processing low quality and low valued hardwoods has been termed "SHOLO" for SHOrt LOG processing. The concepts have been evaluated by scientists of the Northeastern Forest Experiment Station at the Princeton Forest Products Marketing Laboratory at Princeton, West Virginia. They have also provided a technique of evaluating the economic feasibility of a proposed venture for a given set of circumstances of target product, processing system and raw material source.

You need to have a number of things in mind before such a proposed system should be started:

1/ Paper presented at the symposium: Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

2/ Multi-Regional Harvesting Specialist, USFS, Region 3, State & Private Forestry, Albuquerque, New Mexico

3/ July 1976 Colorado State Forest Service, Forest Products Bulletin V 10 #3.

- (1) The product objective must be defined by dimensions and grade if possible. Quality limitations of the round log must be identifiable. Pallet stock, furniture squares, match-block, etc. may be potential products.

- (2) Sale value of products must be established.
- (3) Market values of residues, if present, must be established for both the defective section of stems bucked out and processing residues of the high quality bolts. Pulp chips--cattle feed--bedding flakes, firewood, etc. would be potentials for consideration.
- (4) Potential recoveries of usable high quality bolts and residues must be evaluated as a percent of total volumes handled. A specific cruise, etc. may be necessary to determine this.
- (5) A processing system must be planned to allow processing of the tree stems at a volume rate and estimated cost to meet the objectives of the firm undertaking the venture. Consider various types of breakdown methods--scragg saw, band saw, gang saw, slab saw, trim saws, etc. that could be used to convert the short blocks into the target product. Consider also various possible combinations of equipment.
- (6) An economic analysis must be made to determine if a given system can in fact economically process the available raw material into the target products. If determined not economical, either redesign the processing system into a more efficient configuration or combination of equipment or drop the proposal altogether.
- (7) If the above proposal appears economically feasible, then complete design and layout of the processing system and begin construction.

It may take two or three tries at finding an economical processing unit or system or balance of principal breakdown equipment and secondary processing units but it is important to do this to set up the most efficient system possible for the available resource and target products. Remember we are dealing with a low value log to start with so need to be as efficient as possible.

The physical processing of a low quality tree would be as follows:

1. Fell tree and buck, from between defects (if any), all possible high quality blocks that will produce the target product.

This may be done at the stump or at a landing or by processor or the tree may be handled full length to the mill for debarking before bucking.

2. Transport product blocks to mill. Transport defective pieces to a chipper, flaker, splitter, etc. for processing.
3. Breakdown blocks into product dimensions. This can be done by a 2 or 4 saw circle scragg, twin or quad band saws or standard circle or band saw with appropriate resaw equipment, whichever results in the lowest production costs for the firm's objectives.

Three methods of log breakdown are discussed by Coleman and Reynolds in their 1973 paper NE-279 Sawing SHOLO Logs: Three Methods.

They found that both yields of products and width recovery are affected by the type of breakdown and amount of effort expended to recover material from slabs.

This system has proven effective in the production of pallet parts from low quality trees in the eastern U.S. The high speed production of single pass systems can more than offset the low quality and potentially high defect volume of these stands.

The key element in the process is the identification of the target product(s) with all processing, from the stump, directed toward those products without going through a secondary processing system.

Annotated Bibliography

- 1973 Coleman, Ronald E. & Hugh W. Reynolds
Sawing SHOLO Logs: Three Methods.
USDA Forest Service Research Paper
NE 279
Northeastern Forest Experiment Station
6816 Market St., Upper Darby, PA 19082

A discussion of the results of testing 3 breakdown methods for SHOLO logs.

- (1) Selective method - logs are sawn through and through on a standard circle or gang sawmill.
- (2) Gang method - 4-sided cant produced on a 4-saw circle scragg or quad band then the cant was gang sawed.
- (3) Combination method - same initial breakdown as in 2 but with addition of slab resaw and edger saw.

Highest volume recovery was from selective or combination methods. The selective method produced highest proportion of wider boards.

- 1970 Reynolds, Hugh W. & Charles J. Gatchell
The SHOLO Mill: Make Pallet Parts and
Pulp Chips From Low Grade Hardwoods
USDA Forest Service Research Paper 180 NE
Northeastern Forest Experiment Station
6816 Market St., Upper Darby, PA 19082

Presents the details of one example of a processing system to produce pallet shooks from SHOLO material from low-grade trees. This is only one example that uses sizeable investments with large volume needed to show a profit. Other systems using lesser investment costs and lower volume demands can produce same results.

- 1971 Reynolds, Hugh W. & Charles J. Gatchell
The SHOLO Mill: Return on Investment Vs.
Mill Design
USDA Forest Research Paper NE 187
Northeastern Forest Experiment Station
6816 Market St., Upper Darby, PA 19082

Presents the analytical techniques used to evaluate the profitability of a proposed set of circumstances including mill design, product objectives, and raw material source. Presents method with nomographs and instructions to complete the analysis.

- 1972 Yerkes, Vern P.
SHOLO Can Help Make Use of Low-Quality
Logs.
Forest Industries V 99 #11 p. 40-41
Oct. 1972

Presents an introduction to the SHOLO mill concepts and planning process for mill design and establishment.

Kiln Drying Characteristics Of Studs From Rocky Mountain Aspen And Wisconsin Aspen¹

James C. Ward^{2/}

Abstract.--Aspen studs, 7/4-inch thick, from Rocky Mountain and Wisconsin trees will dry to required moisture contents within similar periods of time under conventional and high temperature kiln schedules. Bacterial wetwood occurs in both Rocky Mountain and Wisconsin aspen and causes severe drying problems from wet pockets, collapse, honeycomb, and ring failure. Presorting green lumber is a suggested solution to the wetwood problem.

SUMMARY

Comparative studies were made of the kiln drying characteristics and related wood properties of aspen from the Rocky Mountains and from Wisconsin. Wisconsin aspen includes both bigtooth and quaking aspen, but quaking aspen is the sole Rocky Mountain species. All sample material was sawed in the form of 2 x 4 studs (1-3/4 inch green thickness) and kiln dried green from the saw under conventional and high temperature schedules commonly used to dry softwood dimension lumber. The conventional schedule had initial dry-bulb (DB) and wet-bulb (WB) temperatures of 180°F and 170°F, respectively. Initial conditions for the high temperature schedule were 235°F (DB) and 200°F (WB). One charge of bigtooth aspen studs was dried with a borderline schedule of 212°F (DB) and 198°F (WB).

Total drying times for aspen studs to reach final required moisture contents less than 19 percent varied by schedule and by the type of wood in each piece. Three types of wood, sapwood, heartwood, and wetwood, were found to occur in both Rocky Mountain and Wisconsin aspen. Given equal drying conditions and comparable types of wood, Rocky Mountain and Wisconsin aspen will dry to required moisture contents within similar time periods.

Sapwood dried at the fastest rate and wetwood at the slowest, while heartwood had an intermediate, but wide range of drying rates. Under high temperature conditions, average times for sapwood, heartwood, and wetwood to dry to 15 percent moisture content were 17, 25, and 30 hours, respectively. The conventional schedule required an average of 90, 115, and 179 hours to dry sapwood, heartwood, and wetwood to 15 percent moisture content. Average drying times using the borderline schedule, 212°F (DB) - 198°F (WB), were only 25 to 30 percent less than drying times under the conventional schedule. Eastern hemlock and white fir dimension lumber, 1-3/4-inches thick, were found to have similar drying times, indicating that aspen studs can probably be kiln dried in mixture with softwoods.

During drying, wetwood in both Rocky Mountain and Wisconsin aspen invariably developed collapse, honeycomb, ring failure or a combination of these three. Sapwood and heartwood did not develop these types of degrade even when subjected to high temperature drying conditions. Wetwood studs dried under the conventional schedule did not appear to have less degrade than wetwood studs dried under higher temperatures.

It is postulated that anaerobic bacteria are responsible for wetwood formation in living aspen trees. Most examples of wetwood formation in Wisconsin aspen could be traced to bacterial invasion of inner or dying sapwood, while wetwood in Rocky Mountain aspen could generally be traced to bacterial invasion of established heartwood. Wetwood-associated bacteria also contributed to the drying problems. Retarded drying rates in wetwood are attributed to occlusion of vessels by bacterial slime and

^{1/} Paper presented at the symposium, Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, CO, Sept. 8-9, 1976.

^{2/} Research Forest Products Technologist, Forest Products Laboratory, USDA, Forest Service, Madison, WI.

related by-products. It should be noted, however, that non-infected heartwood dried at a slower rate than sapwood because of tyloses formation in vessel lumens. Pectin-degrading anaerobes, especially those in the genus Clostridium, were consistently isolated from aspen wetwood and are believed to cause an enzymatic weakening of the bonds between wood cells, thus resulting in collapse, honeycomb, and ring failure.

Problems associated with the drying of wetwood are the major obstacles to successful utilization of aspen for studs. Until such time that techniques can be developed for adequate drying of mixed kiln charges, the best solution to the wetwood problem is to sort out the wetwood studs from studs with normal wood and then dry the various sorts under different methods. This study indicates two wood properties, electrical resistance and green weight, should be investigated further as factors for presorting wetwood.

Aspen Wood And Bark In Animal Feeds¹

Andrew J. Baker^{2/}

Cellulose is the most abundant, naturally renewable material on earth. It and hemicellulose make up about 70% of the dry weight of shrubs and trees. The cellulose of woody plants, however, is largely unavailable to ruminants because of the highly crystalline nature of the cellulose molecule and the existence of a lignin-carbohydrate complex.

The digestibility of aspen wood by ruminants has been estimated to be about 35%. In dairy cow feeding experiments, ground aspen wood appears suitable as a partial roughage replacement in high-grain dairy rations. This would be practical for dairy cows, however, only if other roughages are not available.

The digestibility of aspen wood, and presumably aspen bark also, can be increased to approach the theoretical maximum by various physical and chemical pretreatments.

Aspen bark appears to be equivalent to medium-quality hay if properly supplemented. Its use in sheep and beef cow rations should be considered if other sources of feed are expensive or unavailable.

^{1/} Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

^{2/} Chemical Engineer, U.S. Forest Products Laboratory, Madison, Wis., 53705. The Laboratory is maintained in cooperation with the University of Wisconsin.

The use of whole-tree aspen in growth rations for beef animals is being investigated by L. D. Kamstra, Animal Science Department, South Dakota State University, Brookings 57006. Information on methods of preparation and supplementing aspen bark for wintering rations for beef cows is available from R. D. Goodrich, J. C. Meiske, and J. W. Rust, Department of Animal Science, University of Minnesota, St. Paul 55108.

The following reports on wood and bark in animal feeds are available from Forest Products Laboratory, Forest Service, USDA, P.O. Box 5130, Madison, Wis. 53705:

Baker, Andrew J., Merrill A. Millett, and Larry D. Satter, 1975. Wood and wood-based residues in animal feeds. p. 75-105. In Cellulose Technology Research, Albin F. Turbak, ed. Am. Chem. Soc. Symposium Series 10, Am. Chem. Soc., Washington, D.C.

Fritschel, P. R., L. D. Satter, A. J. Baker, and others, 1976. Aspen bark and pulp residue for ruminant feedstuffs. J. Animal Sci. 42:1513-1521.

Colorado Steers And Aspen Bark¹

Julius A. Fullinwider^{2/}

Abstract.--To assess the practicality of increasing the value of aspen fiber through use of its bark as a livestock feed, feeding trials were conducted at a Colorado feedlot. Weight gains and carcass grades were slightly lower in steers fed aspen bark than those fed alfalfa roughage. Further livestock feeding research is needed to resolve palatability problems encountered.

INTRODUCTION

Western Colorado has 2.3 million acres of aspen type totaling 5.1 billion board feet of aspen sawtimber (Green and Setzer, 1974). Aspen in the Rocky Mountains is generally considered a low profitability species primarily because of, but not limited to, its small diameter at maturity, its crookedness, its low quality due to knots and a general lack of markets for products. Aspen is often the first stand to become established after a disturbance such as fire, logging, or avalanche. It often serves as a "nurse" cover for relatively shade-tolerant conifers such as spruce and fir. If left unmanaged, areas with this short-lived aspen cover will eventually revert to conifers.

Perpetuation of aspen is needed to benefit the following resources:

- To provide habitat for elk, deer, black bear, beaver, woodpeckers, flammulated owl and other non-game animals and birds.
- For aesthetics, which are enhanced by fall color and landscape variety in form and texture.
- To serve as living firebreaks between conifer stands.

- To enhance recreation experience by maintaining a variety of wildlife and plants.

- For watershed improvement provided by fast-growing and extensive lateral root system of aspen.

It is the premise of the work described herein that profitable utilization of aspen bark will encourage total utilization and improve the economic picture for the species and, therefore, will aid in the management of the species. In addition to forest management benefits, the use of aspen bark to replace hay in rations would help to alleviate hay shortages, especially during dry years, and might reduce feed costs in locations far from hay-growing areas.

Using aspen bark for feed is economically appealing because (a) debarking is a common practice at wood processing plants, (b) bark has an associated disposal cost at the mill and (c) handling and pelletizing costs for feed are minimal. Total manufactured costs for aspen bark are estimated to be \$30 to \$40 per ton for a commercial operation compared with hay costs of approximately \$65 to \$85 per ton.

PAST FEEDING STUDIES

Interest in feeding wood to ruminants as a roughage and an energy source dates back to 1920, when Douglas fir and eastern white pine sawdust were fed to sheep and dairy cows (Baker, Millett, Salter, 1975). However, only the University of Minnesota and the University of Wisconsin have reported feeding trials and experimental testing of aspen bark. The desirability of aspen bark for deer, elk, and beaver is well-noted.

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Fort Collins, Colorado, September 8-9, 1976.

^{2/} Forest Products Specialist, USDA-Forest Service, Denver, Colorado.

The University of Minnesota trials involved ensiling the bark before feeding to 15 sheep in three different amounts (Table 1). The bark was not pelleted. Chemical composition of the ensiled poplar bark (moisture free) was measured and is shown in the following tabulation:

Chemical composition of ensiled poplar bark
(moisture free)

Crude protein -----	2.2%
Crude fiber -----	53.7%
P -----	.03%
K -----	.22%
C _a -----	1.16%
N _a -----	.003%
M _g -----	.09%
Fe -----	74.1 ppm
Zn -----	140.0 ppm
Cu -----	7.7 ppm
Mn -----	0.1 ppm
Mn -----	21.0 ppm
B -----	12.7 ppm
Sv -----	44.1 ppm

Digestibility, determined by differences when compared with a basal mixture, was 36.7% (± 1.66 standard error) on a dry-matter basis. The digestibility of hay is around 55%, depending upon its quality.

Table 1.--Performance and ration of University of Minnesota trial for 13 through 48 days

Number of sheep	5	5	5
Average daily feed, kg			
Aspen bark ^{1/}	1.78	1.54	1.34
Soybean meal	.23	.13	.045
Oats	--	.34	.068
Average daily weight gain, kg -	.043	.034	.035

^{1/} 44.4% dry matter

The University of Wisconsin has also reported good success with aspen bark fed to goats (15%, 30%, 45%, and 60% in ration) and has reported higher digestibilities (50%). Further work with sheep at the University of Wisconsin has confirmed these results although, from time to time, some palatability problems were encountered with the sheep.

Trials ending in September 1975 at the University of Saskatchewan in Canada showed that steam and alkali treatments were not successful in raising aspen bark digestibility above 30%.^{3/}

In the spring of 1975, a pilot test of aspen bark feeding as the roughage component of a finishing ration at a feedlot in Montrose, Colorado was initiated. About the same time, aspen feeding trials were planned at South Dakota State University.

TRIAL PREPARATION

Plans

Between March 12, 1975, and June 5, 1975, a project plan, financial plan, cooperative agreement between USDA-Forest Service and Collins Farm feedlot at Montrose, and a cooperative agreement between Collins Farm and participating cattlemen were written.

Bark Procurement

Several logging operations in the Montrose area were cutting aspen on mixed species timber sales. American Excelsior was the one operation cutting only aspen. Their process called for complete removal of all sizes of trees, decking in Olathe, debarking and cutting into 100-inch bolts for later shipment to their Denver plant. A Rosser-type debarker, with a high wood content residue, was in use at this location.

A ring-type debarker, which produced cleaner bark and had higher bark recovery possibilities, was located at Silver Tip Studs in Montrose. Arrangements were made to have the American Excelsior aspen logs delivered to Silver Tip Studs and debarked at a cost of \$4 per thousand board feet. Twice during the summer the logs were decked, scaled and debarked to obtain bark volumes needed for the feeding trials. Logs were debarked from two different sources: Little Cone Mountain near Sawpit, Colorado, and the Buckhorn area near Ridgeway, Colorado.

The bark was easily removed and ranged in size up to three square foot strips. No

^{3/} Unpublished study

evidence of any disease was found. Some wood, particularly knots, was broken off by the debarker, but was removed before the bark was pelleted. Bark samples were taken frequently throughout debarking, placed in an air-tight container, and shipped to Fort Collins for moisture content analysis. Next the bark was trucked from the collection hopper to a drying area.

Little Cone Mountain bark was dried in a lumber dry kiln with fans operating and kiln doors left open. No heat was applied. Buckhorn bark was air-dried in piles at one end of the Silver Tip Studs log yard. Air drying was found to be the most feasible way to handle the large volume of bark. Several days of 70°+ weather were required to dry the bark from 95% moisture content (oven-dry basis) to 15%. Without periodic "mixing", piles of bark heated to some extent. Spreading bark on an asphalt surface for rapid drying would be suitable, alleviating the need for mixing. A rotary corn dryer would probably be the best method for bark drying.

Bark sample data follows:

	<u>Little Cone</u>	<u>Buckhorn</u>
Scaling sample yield:		
No. of logs	130	155
Bark Volume	503.28 ft ³	434.86 ft ³
Wood Volume	2427.13 ft ³	2296.06 ft ³
Bark % of Total	17%	16%
Moisture content: ^{1/}		
Ave.	95%	91%
Range	60%-122%	78%-116%
Specific gravity		
Ave.	0.448	not
Range	0.38-0.57	determined
Total yield:		
No. of logs	165	686 ^{2/}
Bd. ft. (Scribner)	14.1M	43.4M
Green tons of bark	9.6 tons ^{3/}	28.5 tons ^{3/}

^{1/}Obtained from bark conveyor samples and log deck samples. Moisture content is oven-dry basis, rather than original-weight basis. For instance, an oven-dry M.C. of 100% would be an original-weight M.C. of 50%.

^{2/}Exclusive of 39 logs with no bark.

^{3/}These figures represent about 75% of total bark tonnage. About 25% of the bark was lost in handling prior to debarking due to bark slippage on logs cut during the spring.

Bark Processing

Pelleting the bark roughage was determined to be the most accurate and easiest way of handling and measuring. Ute Mills of Montrose was very cooperative in processing the aspen bark. No major problems were encountered. Hammermilling of the bark caused more stress on the equipment than pelletizing. Moisture content of the bark was critical during hammer-milling and needed to be near 15%. Both 1/4-inch diameter and 3/8-inch diameter pellets were made with no additives. The 3/8-inch pellet was used in the trials as recommended by Dr. John Matsushima of Colorado State University. Aspen bark was processed and delivered by Ute Mills upon request from the feedlot throughout the trials. Pellets were stored in sacks inside a building at the feedlot.

Cost of Aspen Bark Pellets

	<u>Cost/Ton</u>
Debarking	
20.35 tons processed	\$11.43
.65 waste	
21.00 tons total	
Hauling (storage and drying)	3.10
Hammermilling and pelletizing	18.00
Handling (from storage to mill and feedlot)	2.00
	<u>\$34.53</u>



Raw aspen bark spread for drying

Hay Procurement and Processing

Sun-cured alfalfa hay was purchased through Ute Mills. All hay was assumed to be equal in protein content. The hay was processed through the same mill and 3/8-inch diameter pellets were delivered to the feedlot as requested.

<u>Hay Cost</u>	<u>Cost/Ton</u>
Hay	\$65.00
Pelletizing	18.00
Handling	2.00
	<u>\$85.00</u>

Procurement of Steers and Feedlot

A well-operated feedlot with good record-keeping procedures was located in Montrose, Colorado. Collins Farms feedlot feeds several thousand cattle annually, has up-to-date equipment and techniques and was willing to cooperate in the project.

Two-hundred steers were solicited through local ranchers to fill the four feeding trial pens. The steers were split into pens as evenly as possible by breed, owner, and weight. The following livestock owners cooperated in the trials: Currier, Collbran (100 head), Hughes Brothers, Norwood (28 head), Raymond Snyder, Norwood (22 head), Jack Dixon, Gunnison (25 head), and Collins Farms, Montrose (25 head).

Public Information

An information booth was set up for display at the Colorado Cattlemen's Association convention, June 19-21, 1975. The purpose of the booth was to inform convention attendees of the why and how of the aspen bark trials. The booth consisted of a series of photos showing the processing of the bark from tree harvest to cattle feeding. Samples of raw, hammermilled and pelleted bark were available for observation. Some people actually tasted the pellets and decided they might be taster's choice to a beaver, but definitely not to them, personally. Literature describing these trials and similar research was available to the public. To answer any questions that might arise, the booth was manned by Forest Service personnel Tom Weldon, Jim Free and Wendell Turner.

Information regarding the trials appeared in Montrose, Grand Junction, and Denver newspapers. Additional articles appeared in other magazines and newspapers.

FEEDING TRIALS

Dr. Matsushima designed the initial feeding ration for the trials, monitored the division of steers into pens, made later feeding ration changes and graded carcasses at the end of the trials.

The two-hundred yearling steers were divided into four pens. Two of the pens were to be fed aspen pellets as roughage and the

and the other two were to be fed alfalfa pellets. On June 17, 1975, the steers were ear-tagged, pen-branded, weighed and assigned to one of the four pens on a rotational basis. All of the steers were given the regular treatment of grub and rednose control, and were given Lepto vaccinations prior to weighing.

Approximately 50% of the steers were Limousine-Hereford or Charolais-Hereford crosses, 15% Hereford-Angus cross, with the balance composed of Herefords or mixed crosses. Considerable variation was noted in the size of steers with starting weights varying from 500-950 pounds. The average initial weights were 667 pounds for the aspen group and 673 pounds for the control or hay-pellet group.

The rations for both groups were designed to contain approximately 11% protein on an air-dry basis. The guidelines for feeding each group were set up at the beginning of the feeding trial. Six rations for each group were planned so that, as the feeding period progressed, energy content in the ration would gradually increase. The initial ration (Ration 1) for the aspen group contained approximately 25% aspen pellets and the finishing ration (Ration 6) contained approximately 5% aspen pellets.

Because difficulty was experienced in getting the steers to consume the intended levels of aspen pellets, the rations were modified. Consequently, feed consumption shown later in the text will not correspond to that originally planned.

The original plan was to feed the steers on aspen bark the following: aspen bark pellets, corn silage, flaked corn, and protein supplement. As the feeding period progressed, the corn silage was to be gradually removed so that aspen pellets would serve as the only roughage. However, there was difficulty in getting the steers to consume the desired level of feed. This in turn, was affecting weight gains in the steers. The level of aspen bark was subsequently decreased and haylage (ensiled alfalfa hay) was added to the ration so that the roughage level in the ration would correspond to the control group. Corn silage was increased during July, and then dropped from the ration until November.

On June 30, 1975, two weeks after the trials started, the steers were "backing off" the rations shown in Table 2.

The difference of 2.3 pounds of dry matter intake per head between the two groups had an adverse effect on the gain of the steers fed aspen bark. Therefore, at this point, the recommendation was made to decrease the amount of aspen pellets in the

Table 2.--Feeding Ration as of June 30, 1975

	CONTROL			ASPEN		
	Daily Consump.	Dry matter ^{1/} Consump.	TDN ^{2/} Consump.	Daily Consump.	Dry matter ^{1/} Consump.	TDN ^{2/} Consump.
Corn	9.8	8.82	7.84	9.6	8.6	7.68
Protein	0	0	0	4.2	3.8	2.94
Hay pellets	9.8	8.82	4.9	0	0	0
Corn silage	7.68	2.3	1.55	10.0	3.0	2.0
Aspen pellets	0	0	0	2.5	2.2	1.25
TOTAL		19.94	14.29		17.6	13.87

^{1/} Dry matter values used: 90% D.M. for all feed except for corn silage which 30% D.M. was used.

^{2/} TDN values used: Corn = 80%; protein = 70%; hay and Aspen pellet = 50%; corn silage = 20% (on natural basis).

ration. On July 1, 1975, the aspen pellets were reduced to two pounds per head per day. After a couple of weeks, the feed consumption began to increase and consequently, the aspen pellet consumption increased back up to around 2.6 pounds per head daily. However, on a percentage basis, the level of aspen in the ration had not increased. About July 1, salt was mixed with aspen bark in the pellets. Then, during mid-August, the condition of the steers and the feed consumption records were examined. A decision was made to drastically reduce the quantity of aspen pellets in the ration.

On August 16, 1975, the aspen pellets were reduced to a level of less than one pound per head daily. Then, as the feed consumption increased, the consumption of aspen pellets increased to about 1.25 pounds and remained at this level for the remainder of the feeding trial.

The aspen pellets were estimated to be around 3% protein, but the composite figure for several batches of the pellets turned out to be 4.81% on an as-is basis or 5.0% on dry matter basis. The fiber content of the aspen pellets was 28.81% on natural basis or 30.3 % on dry matter basis.

RESULTS

The major findings of the feeding trial are reported in Table 3. The gains, feed efficiency and the slaughter-carcass data are all reported in the table. Feed cost comparisons are shown.

As noted in Table 3, the steers fed aspen bark pellets gained 4.15% less than the control steers (2.77 pounds daily gain versus 2.89 pounds). The lower gain must be attributable to the lower feed consumption encountered during the early part of the feeding period. Once

the level of aspen in the ration was decreased, the total feed consumption increased. The steers that were fed aspen bark showed a marked increase in corn consumption during September, October, and November. This accounts for the larger figure shown for the average daily corn consumption (16.71 pounds flaked corn for aspen steers versus 15.88 pounds corn for control steers). Table 4 shows cost/lb. of feed and daily cost/head for feeding. Table 5 shows feed consumption by month.

A larger quantity of protein supplement was included in the ration for the steers fed aspen bark because of the low protein content in that feed. During the first 80 days, this commercial protein supplement (40% protein with 20% protein equivalence from urea) was fed to the aspen group. From September 7, 1975, a commercial protein supplement (32% protein with 19% protein equivalence from urea) was fed to both groups.

Since the steers on aspen pellets gained less and consumed more feed than the control steers, the control steers were 5.19% more efficient in their gains.



Trial steers consuming aspen bark ration

Table 3.--Aspen Feeding Trial Results (June 17, 1975 to November 23, 1975)

	Control	Aspen
Number of Steers	100	99 ⁸ /
Number of Days Fed ⁷ /	149	147
Initial Weight, Lbs.	673	667
Final Weight, Lbs.	1100	1074
Total Gain, Lbs.	427	407
Average Daily Gain, Lbs. ⁹ /	2.89	2.77
Average Daily Ration, Natural Basis, Lbs.:		
Grain (Flaked Corn)	15.88	16.71
Protein Supplement (Commercial)	0.91	2.43
Aspen Pellets	---	1.84
Hay Pellets (Alfalfa)	8.41	---
Corn Silage ¹ /	1.26	3.31
Alfalfa Haylage ² /	2.43	12.89
Air Dry Feed, Lbs.	26.55	27.13
Feed Required/Lb. Gain	9.25	9.79
Dressing Percent ³ /	62.9	62.8
Liver Condemnation, %	29.7	12.24
USDA Carcass Grade ⁴ /	15.0	14.9
% Choice	27.7	18.4
% Good	73.0	82.5
Fat Thickness, In.	0.58	0.57
Ribeye Area, Sq. In.	13.1	13.0
Kidney, Pelvic Fat, %	2.5	3.1
% Cutability ⁵ /	50.16	50.09
Yield Grade ⁶ /	2.95	2.97

¹ Corn Silage = 70% moisture

² Haylage - 60% moisture

³ Cold carcass weight divided by delivered weight

⁴ USDA Grade: 16 = Low Choice; 15 = High Good

⁵ % of carcass weight in boneless, closely trimmed, retail cuts from round, loin, rib, and chuck.

⁶ Yield grade 2 = 52.3 to 50.3% cutability

⁷ Approximately half the steers were fed for 134 days, and the other half for 160 days

⁸ Steer Number 147 was removed from this pen July 19, 1975

⁹ Statistically significant as 5% level



Trial steers in feedlot, one week before first shipment

Table 4.--Feed Cost (1975)

	CONTROL	ASPEN	
	1975 ¹ / Cost/Lb.	Daily Cost/Head	Daily Cost/Head
Average Daily Ration, Natural Basis, Lbs.:			
Grain (Flaked Corn)	\$0.060	\$0.95	\$1.00
Protein Supplement (Commercial)	0.080	0.07	0.19
Aspen Pellets	0.017	---	0.03
Hay Pellets (Alfalfa)	0.042	0.35	---
Corn Silage	0.011	0.01	0.04
Alfalfa Haylage	0.015	0.04	0.19
TOTAL (Natural Basis)		\$1.42	\$1.45

¹/Costs for flaked corn, protein supplement, corn silage, and alfalfa haylage from Collins Farms; costs for aspen & hay pellets from USFS calculations.

Table 5.--Feed Consumptions by Month (as fed basis)

	STEERS FED ASPEN BARK					
	Protein Supplement	Flaked Corn	Corn Silage	Haylage	Aspen Bark Pellets	Salt
6/17/75- 6/30/75	5,680	9,300	14,550	--	5,330	22
7/01/75- 7/31/75	8,880	40,390	33,480	37,440	7,910	109
8/01/75- 8/31/75	8,095	49,870	---	67,200	6,110	48
9/01/75- 9/30/75	5,220	53,740	---	40,750	3,000	--
10/01/75-10/31/75	5,200	63,670	---	29,580	3,350	--
11/01/75-11/23/75	2,300	26,240	100	12,580	1,360	--
TOTAL	35,375	243,210	48,130	187,550	27,060	179

	CONTROL STEERS					
	Protein Supplement	Flaked Corn	Corn Silage	Haylage	Aspen Bark Pellets	Salt
6/17/75- 6/30/75	---	13,190	10,220	---	13,260	30
7/01/75- 7/31/75	---	42,900	8,440	10,160	29,520	58
8/01/75- 8/31/75	---	48,840	---	20,590	25,360	20
9/01/75- 9/30/75	4,700	50,840	---	5,200	21,560	--
10/01/75-10/31/75	6,070	54,660	---	---	24,260	--
11/01/75-11/23/75	2,760	24,620	---	---	10,570	--
TOTAL	13,530	235,050	18,660	35,950	124,530	108

The steers in the feeding trial were shipped to Denver on three different dates. The first group, consisting of 44 control and 45 steers fed aspen bark, were shipped on October 29, 1975. Since a high percentage of the steers did not make the choice grade, it was decided to delay the shipment on the balance of them. Four weeks later, the balance of the steers were slaughtered. Based upon the records, the extra four weeks of feeding didn't improve the carcass grades: 22% of the steers fed aspen bark were graded choice in the first ship-

ment, and 15% graded choice in the second shipment. In comparison, 29% and 23% of the control steers were graded choice in the first and second shipments, respectively.

It is difficult to determine why a larger percentage of the steers in either group did not grade choice. Degree of marbling is the major factor which determines the quality grade (to grade choice, good, etc.). Available data indicates that yearling steers fed either for 130 days or over or with grain

consumption exceeding 2,200 pounds per head should grade 70% choice or better. In both the group fed aspen bark and the control group, the grain consumption exceeded this level (actual corn consumption was 2,432 pounds for the group fed aspen bark and 2,351 for the control steers).

In summary, the results of the trials were as follows:

- Liver condemnation was lower in the steers fed aspen bark. Condemnation percentages were identical to a recent Canadian study.
 - Sickness was noted in only one of the steers fed aspen bark.
 - Gain was 4.15% less in the aspen bark fed steers, and was probably due to lower feed consumption during the early part of the feeding period.
 - Even though larger amounts of corn silage and alfalfa haylage were fed than planned, the daily feed cost per head for the steers fed aspen bark was only 3¢ higher than the control group.
 - Choice carcass grade was 9.3% lower in the aspen bark group than in the control group.
 - Carcass data, other than liver condemnation, gain, and grade were very similar for the two groups.
- The following problem summary should help facilitate planning of possible future feeding trials. Problems were:
- Delay in planned delivery of aspen logs to the mill due to wet spring logging conditions.
 - Bark loss (about 25% of the total) between the stump and the mill due to bark slippage on logs cut in the spring.
 - Need for bucking tree-length aspen into shorter lengths to accommodate the ring debarker at Silver Tip Studs due to the high amount of crook and sweep in the aspen.
 - Lack of adequate available bark drying facilities at Montrose
 - Difficulty in hammermilling bark above 15% moisture content. This was attempted once.
 - Steers "backing off" the aspen bark pellet ration, which resulted in modifying the ration to maximize weight gain on these steers
 - Low % of choice grade in both the control and the aspen bark steers.

- Because of ration changes, the proportion of grain to roughage between the two rations are not comparable. Consequently, the differences in weight gain of the steers, feed consumption, carcass grades and all the other parameters compared, cannot necessarily be attributed to the aspen bark included in the ration.

CONCLUSIONS

Further research in feeding aspen bark to steers is needed to help resolve the question of palatability and other problems encountered in this pilot test. It is evident that some other ingredient, such as dehydrated hay, should be mixed in with the aspen bark before pelleting.

Wildlife (deer, moose, elk, antelope, mountain sheep) feeding tests are being conducted with aspen bark by Wyoming Game and Fish near Wheatland, Wyoming. A report will be written upon completion of the trials. Further investigative work should be done in this area, if indicated from the Wheatland trials.

LITERATURE CITED

- Baker, Andrew J., Millett, Merrill A., Satler, Larry D.
1975. Wood and wood-based Residues in Animal Feeds. FPL Technical Article.

ACKNOWLEDGEMENTS

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- Wendell Turner, Range Conservationist, USDA-Forest Service, Montrose, Colorado.
- John Minow, Deputy Director, Range and Wildlife Management, USDA-Forest Service, Denver, Colorado.

Aspen Veneer And Plywood¹

Harry E. Troxell^{2/}

Abstract.--The aspen resource in the Rocky Mountain region never has been utilized to its potential. The wood properties of this fast-growing and short-lived species are reviewed as a source of veneer. Aspen is a low density hardwood species with specific gravity falling within the range of .30-.44. The species properties are suitable for veneer with the typical veneer logs being about 10-14 inches in diameter. The creamy-white sapwood comprises the major portion of the cross-sectional area of the stems. There is a tendency for the veneer surfaces to be fuzzy due to tension wood. Veneer drying can be accomplished with a moderate degree of success. Some aspen veneer has an attractive figure and can be selected for decorative panels. It makes good core and crossband material. It is a preferred container wood and suitable for stamped veneer items. The light color, facility of cutting, ease of gluing and nailing and uniform texture are assets which warrant its consideration for use as veneer species.

A program which considers the possible uses of aspen in the Rocky Mountain region should not overlook veneer and plywood. The aspen resource, as pointed out by previous speakers, has never been utilized to its potential. The "coming age of wood" does not mean an easy task lies ahead for utilizing previously little-used species but rather opportunities are there to challenge the insatiable imagination of our industry to couple the technologies of growing, harvesting, processing and marketing a species that has technical properties desirable for the needs of our society. Continued effort and education of the general public is necessary to use efficiently and effectively the aspen resource. We must learn to adjust to a changing resource base. We as educators, researchers, and industrial users of the wood resource must create the kind of programs and services designed to bring about better utilization of aspen.

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³/Refers to Literature Cited.

In order to use Rocky Mountain aspen for veneer and plywood it is essential to know the volume, size and form of the trees as well as the physical and mechanical properties. Lutz (3)³ says the final judgment of a veneer wood is best made on the basis of veneer cutting and drying evaluations made from representative logs.

The wood and log characteristics that affect the quality of aspen veneer are the uniformity at which the veneer can be cut, the surface roughness and the freedom from buckling or wrinkling when green as well as when dry. The significant characteristics of making face veneers is the ability to control figure, color and depth of checks. Natural defects of knots, splits and presence of decay and stains are even more limiting to face veneers. For core and crossband material aspen has properties that make it suitable. The veneer and plywood product standards currently being used in the United States recognize aspen for hardwood and decorative plywood (9) and for construction and industrial plywood (10).

In the hardwood and decorative plywood standard the wood species are grouped on the basis of specific gravity and aspen is included with those species whose specific gravity is less than 0.42. In the construction and industrial plywood standard it is found in

the Group IV woods. The grouping in this standard is based on strength, specifically, modulus of rupture, modulus of elasticity, compression parallel-to-the grain compression perpendicular-to-the grain and shear. Group I represents the strongest and stiffest species. To meet Group I use requirement, aspen for construction and industrial plywood for a 32-inch sheathing and a 16-inch floor spacing use would have to be one-quarter-inch thicker.

The physical properties of aspen of interest to veneer producers are specific gravity, moisture content, permeability, shrinkage, extraneous, cell contents, figure, odor, cell size, type and distribution. Most Rocky Mountain aspen falls within a range of specific gravity of 0.30-0.44.

A comprehensive study establishing the specific gravity for western aspen has never been conducted. Wengert (7) reported from limited sampling from sites classes 1 and 2 the following specific gravities:

Source	S.G.*	S.G.**
Sapwood	0.384	.43
Heartwood	0.387	.43

* green volume, oven-dry weight

** oven-dry volume and weight

The above values are consistently higher than those reported by Markwardt and Wilson (5) for the Rocky Mountain aspen. The earlier information had been determined from six New Mexico trees displaying a growth rate of 7.3 rings per inch, nearly 3 times the average observed by Wengert (7). It appears that the suggested range of specific gravity perhaps represents the best information available.

The moisture content of aspen, like many species varies drastically depending upon the season of the year. Wengert (7) states that typical average values for the Rocky Mountains to be 74 percent for the heartwood, 91 percent for the sapwood, and 96 percent moisture content based on the oven-dry weight of the wood. Log storage in the woods results in very little loss of moisture if the bark remains intact. Some checking due to drying should be expected for logs when the ends are exposed to direct sunlight and wind.

Data for aspen indicates comparative low shrinkage average shrinkage values: volumetrically, 11.5 percent, radially, 3.5 percent and tangentially, 6.7 percent in drying from green to oven dry conditions. Normally tangential shrinkage is about twice that observed radially. Longitudinally

shrinkage of wood normally is very slight and generally ignored. Aspen frequently has tension wood which may result in abnormal longitudinal shrinkage. This can cause noticeable warping of veneer.

The typical Rocky Mountain aspen stands will produce logs from 10-18 inches in diameter. They have only a slight taper, some crook, some shake and about one-fourth to one-third of the cross sectional area will be heartwood (1). Aspen heartwood, compared to the sapwood, is slightly darker in color and the permeability is much less. Wengert (6) reports the heartwood vessels are heavily occluded with tyloses.

The presence of decay, tension wood, knot patterns, wetwood and stains in the wood does limit the veneer potential of the logs. Lutz (4) in a northern Minnesota veneer yield study found 43 percent of aspen veneer to be of poor quality; 20 percent possessing small, tight knots and other defects and that about 37 percent of the veneer was free from defects. It is reasonable to assume a similar relationship could be obtained from Rocky Mountain aspen.

The volume yields for Lake States aspen were made by Bulgrin et al (2) at the U. S. Forest Products Laboratory, Madison, Wisconsin. Recently a 50-log exploratory study of Rocky Mountain aspen was conducted. The results of exploratory study were similar to those reported in the 1966 research paper as follows:

Bolt diameter (inches)	Veneer yield (sq.ft.--3/8- inch basis)	Volume recovery factor
8	25.0	2.5
9	32.4	1.6
10	41.6	1.4
11	56.1	1.9
12	76.0	1.9
13	95.9	1.9
14	108.3	1.8
15	108.0	1.5
16	118.8	1.5

Because of the relatively low density of the wood, the presence of tension wood and wetwood, some difficulty is experienced in cutting veneer which is free from having fuzzy surface. Veneer cutting techniques of cooling veneer bolts to 5°C (40°F) prior to cutting, or using an extra hard knife, or run cold water between the knife and pressure bar are outlined as remedies by Lutz (4). Due to the presence of decay and wetwood some difficulty is experienced with the twisting out of the chucks in the lath.

Aspen veneer requires a slightly longer time to dry the veneer than most hardwood species due to the high original moisture content. The presence of tension wood does cause some buckling of veneer. Wetwood in aspen subject it to checking and collapse during drying. Aspen veneer which is free from tension wood and wetwood will dry flat.

An overview of the relative suitability of aspen for various uses would indicate that it is best suited for decorative plywood paneling, inner plies for plywood, container veneer and plywood and high valued stamped veneer products. The use of aspen for structural plywood has some limitations: namely, the comparative strength properties, the log sizes, the veneer yield and the cost of producing plywood.

SUMMARY

Aspen has many characteristics which make it desirable from veneer and plywood production. The relative low density and soft texture of the wood, the ease of machining, the stability of the wood, the facility of gluing, freedom from odor and the pleasant appearance of wood surface are all features which focus attention toward aspen veneer and plywood products. Important limitations to be considered in the use of aspen are the small logs, relatively low yield, the cost of harvesting and processing and the comparative lower strength properties of aspen when compared to other veneer species.

In spite of the many factors, both technical and economical, that need to be answered in order to develop an aspen veneer and plywood production in the Rocky Mountain region, sufficient evidence exist that full utilization program for the aspen resource should be directed to veneer and plywood. Successful harvesting and processing methods have been developed for other little-used species that have similar limitations as aspen. We need to now point attention to aspen as a veneer species.

LITERATURE CITED

1. Baker, F. S.
1925. Aspen in the central Rocky Mountain region. USDA Dept. Bull. No. 1291. 45 p.
2. Bulgrin, E. H., K. A. McDonald and C. L. Vaughan.
1966. Veneer yields from Lake States quaking aspen. USDA For. Serv. Pap. FPL 59. 8 p.
3. Lutz, J. F.
1971. Wood and log characteristics affecting veneer production. USDA For. Serv. Res. Pap. FPL 150. 31 p.
4. _____
1972. Veneer species that grow in the United States. USDA For. Serv. Res. Pap. FPL 167 p.
5. Markwardt, L. J. and Wilson, T. R. C.
1935. Strength and related properties of woods grown in United States. USDA Tech. Bul. No. 479. 108 p.
6. Wengert, E. M.
1976a. Detecting heartwood and sapwood in aspen. (paper submitted to Forest Products Journal).
7. Wengert, E. M.
1976b. Guidelines for harvesting, utilization and marketing of Rocky Mountain aspen (Populus tremuloides Michx.). (In manuscript).
8. _____
1976c. Properties and characteristics of aspen that affect utilization in the Rocky Mountains. (submitted to the Journal of Forestry).
9. USDC.
1971. Hardwood and decorative plywood. Voluntary Product Standard PS 51-71.
10. USDC.
1974. Classification of species for construction and industrial plywood. Voluntary Product Standard PS 1-74.

Perspective On Particleboards From *Populus* spp.¹

Robert L. Geimer^{2/}

Populus species particleboards have a high compression ratio resulting in high bending strength. Their low-porosity edges, advantageous in furniture manufacture, dictate close moisture content control in production.

Aspen roundwood is the primary raw material for composition structural sheathing. *Populus* utilization will likely increase as material sources expand and as new products develop.

Aspen (*Populus* spp.) is considered to be an excellent raw material for manufacturing particleboard. Some characteristics which favor its use in particleboard are a relatively small springwood to summerwood density gradient which permits quality flaking and uniform drying, the lack of resinous substances which enhances good adhesive bonding, and the light color which is esthetically pleasing to many users.

Whereas aspen is only one of several under-used hardwoods available in this area, its low density characteristic makes it more desirable for particleboard furnish than a denser species such as birch. An important difference is in the bending strength properties. An aspen particleboard averages 34 percent stronger in bending than a birch board at several levels of resin content (fig. 1).^{3/} The same trend is observed when other manufacturing variables which affect bending strength are varied. An aspen board is approximately 1400 psi stronger in bending than a similar birch board at various

flake thicknesses and board densities (figs. 2 and 3, respectively).

Aspen's strength advantage is attributed to its high compression ratio, i.e., board density to species density. Because aspen is lighter in weight than birch, more flakes (of the same thickness) are needed to obtain the same weight board. The aspen flakes are pressed to more intimate contact than are birch flakes and consequently better adhesion occurs. The strength-compression ratio relationship is well illustrated in other work done at Forest Products Laboratory (Vital et al. 1974) where species of different densities were mixed in varying amounts and boards were made at constant compression ratios (fig. 4).

Besides increasing strength, the high compression ratio of a low density species also results in a board with a low porosity or "tight" edge which is of considerable importance in the furniture trade. The same condition, however, restricts steam release during pressing of aspen boards causing "blows" to occur. Moisture content must, therefore, be closely controlled in the manufacturing process, especially when large flakes are used as in wafer boards. Lower mat moisture content, as well as good resin dispersion, is achieved by using powdered resins in the production of aspen wafer boards.

Related work at the Laboratory during the past few years verifies the excellent performance of aspen in obtaining a board which is strong in bending, compression, and tension parallel to the grain, and shows that aspen particleboard in comparison to the higher density hardwoods tends

^{1/} Paper presented at the symposium "Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains," Ft. Collins, Colorado, Sept. 8-9, 1976.

^{2/} Geimer is a research Forest Products Technologist at USDA Forest Service Forest Products Laboratory. The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

^{3/} Haskell, H., Heebink, B. G. How the physical properties of flake-type particleboards are affected by the species of wood, flake dimension, binder content, and density. Unpublished report. Forest Products Laboratory, Madison, Wis.

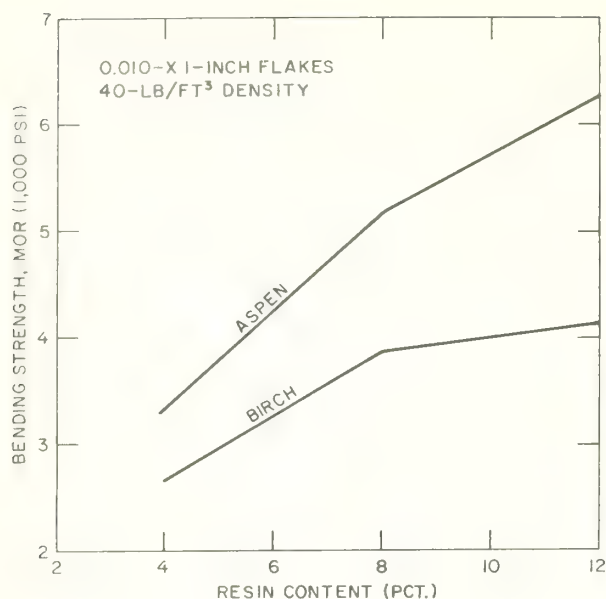


Figure 1.--Bending strength vs. resin content.

to have less linear expansion, but more thickness swelling and a lower internal bond strength. As shown in figures 1, 2, and 3 the board properties can be changed by varying construction details. A variety of layered boards has been made in laboratories to obtain board properties optimum for applications such as furniture corestock, mobile home flooring, or exterior sheathing.

Exterior sheathing is the market in which most of the recently developed aspen wafer boards are finding an outlet. In some areas, wafer board is being marketed as a decorative panel at a substantially higher price. At the present time, there are six plants in Canada and one plant in the United States using aspen to manufacture wafer board. The rapid expansion of the wafer board industry in Canada has created a production capacity almost double the consumption rate. Efforts are currently being made to market the Canadian product in the United States.

Use of aspen is not peculiar to wafer board mills (table 1). The Westvaco plant in Tyrone, Pa., used this species for interior-type boards, until the local supply was exhausted. Columbia Forest Products, located in Sprague, Manitoba, used aspen as its raw material until it burned down a few years ago. Several other Canadian mills use aspen in their furnish. In the Lake States, three mills are currently producing all or partially aspen boards. Publishers Paper Company in Virginia, Minn., produces an all-aspen, phenolic-impregnated paper-overlaid board for exterior siding. The other two mills, Weyerhaeuser in Wisconsin and U. S. Plywood-Champion Papers, Inc., in Michigan, market mainly interior-

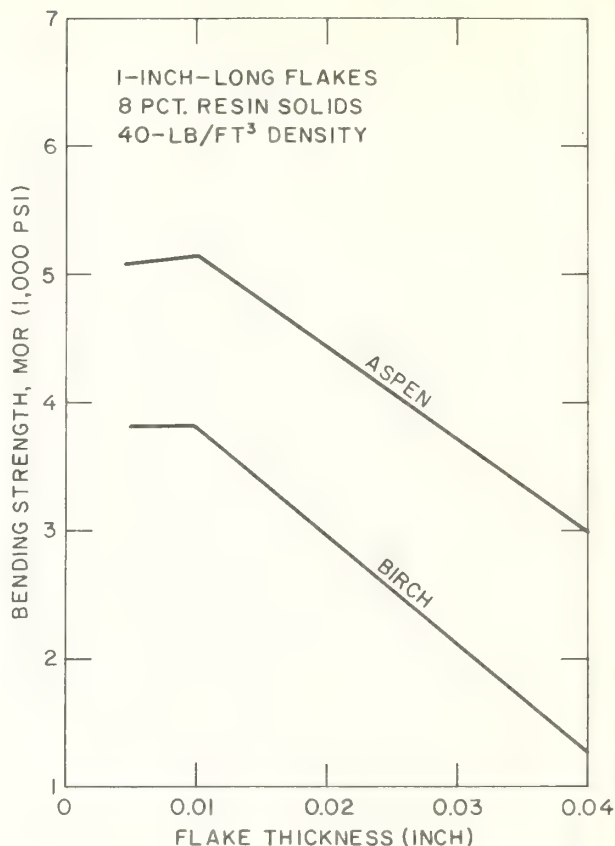


Figure 2.--Bending strength vs. flake thickness.

type boards to the furniture, case goods, and mobile home industries.

It is interesting to note that while both of these mills were originally designed to use roundwood, economics have justified product and process changes necessary to utilize mill and forest residues.

The shift to using mill waste led to plant design changes in receiving and processing equipment suitable for handling wood in the bulk form of chips. Recent advances made in chipping of whole trees in the forests has created a new source of raw material which appears to be cheaper and which has, in some cases, doubled the per-acre yield. The use of whole-tree chips has not been without problems. Dirt and grit have dramatically shortened flaker knife and saw blade life. Reduced flake length, increased fines, and a higher percentage of bark tend to reduce strength and increase glue consumption, while less control of species mix causes variations in production control. Despite these disadvantages, economics dictate that whole-tree chipping will provide an ever-increasing portion of the raw material used by particleboard mills.

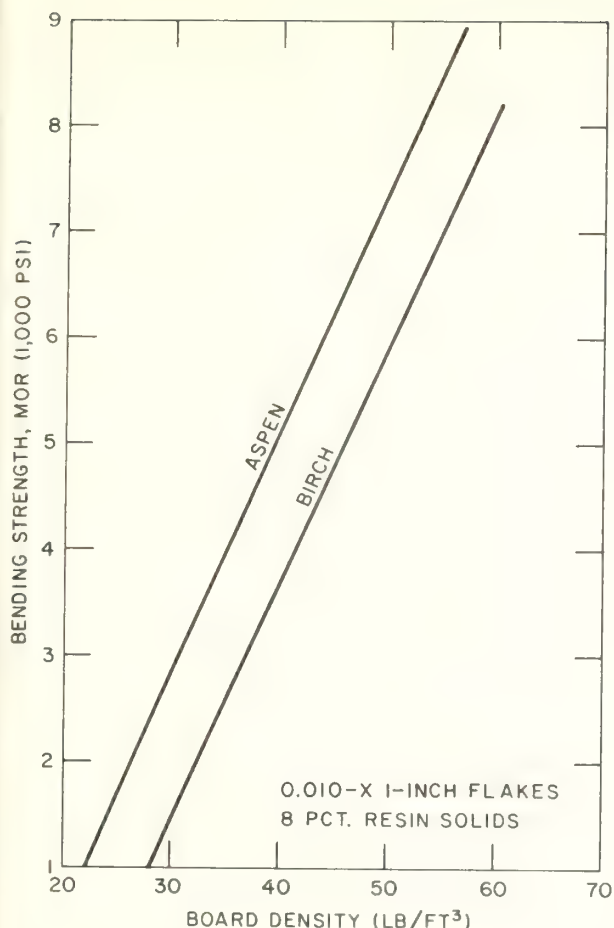


Figure 3.--Bending strength vs. board density.

Whole-tree chips currently produced are of a size suitable for making interior type boards. Increasing the chip size (to "maxi-chips" or "fingerlings") (Heebink 1971) permits cutting of large flakes which can be used in the manufacture of exterior structural flakeboards. The technique is currently being used commercially to cut large softwood chips into flakes which are, in turn, made into a directionally oriented flakeboard used as the core layer of a composite particle-veneer board. The technique has also been used at Forest Products Laboratory for studies on use of 3- to 6-year-old hybrid poplar clones as raw material for particle-board. Although this material contained over 30 percent bark, boards with excellent strength qualities were obtained (table 1).

The need for additional sources of raw material for current production is becoming more urgent as present supplies of mill waste are reduced through greater efficiency or are captured by competing particleboard mills, papermills, and energy-producing operations. As the quantity of high-grade lumber decreases in the face of rising

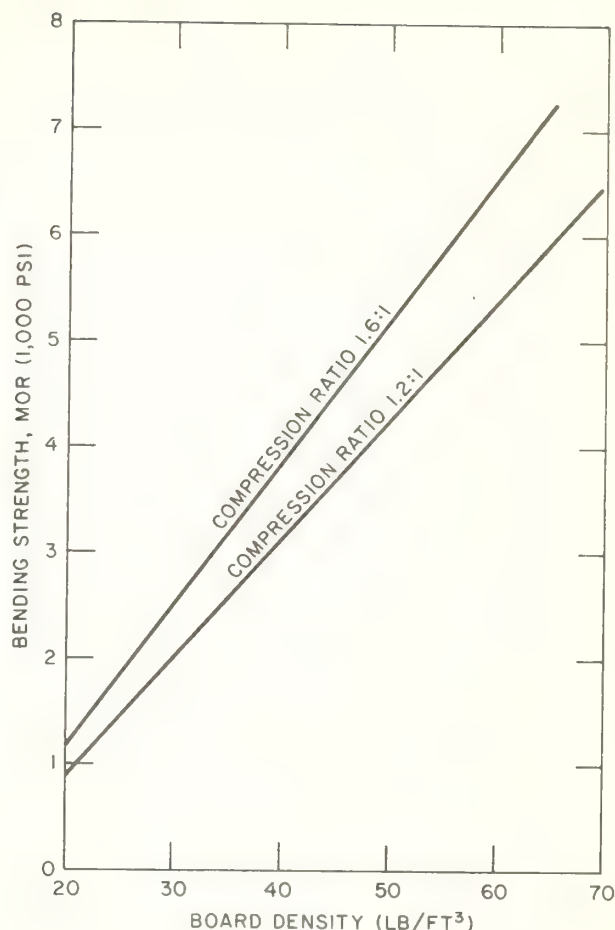


Figure 4.--Bending strength as a function of board density and compression ratio.

demands, it is foreseeable that reconstituted products will be developed which are not mere substitutions for scarce items but rather will be designed for specific applications. Incorporation of such features as flake orientation, density control, and molded shapes will create high-value products. Development of these products will create a demand for an even greater raw materials supply from a versatile raw material--wood.

LITERATURE CITED

- Heebink, B. G.
1971. Forest residues: Future source of particleboard. *Wood and Wood Products* 76(11):26-28.
- Vital, B., W. F. Lehmann, and R. S. Boone.
1974. How species and board densities affect properties of exotic hardwood particleboards. *For. Prod. J.* 24(12):37-45.
- Wood and Wood Products.
1970. *References Data/Buying Guide*. p. 62-71. Wood and Wood Products, Chicago, Ill. Oct.

Table 1.--Properties of Some Commercial and Laboratory Particleboards Made From Aspen

Board			Properties					
Producer	Species	Type	Density	MOR	Screw Holding		Linear Expansion	Internal Bond
					Face	Edge		
			<u>Lb/ft³</u>	<u>1000 psi</u>	<u>Lb</u>	<u>Lb</u>	<u>Pct</u>	<u>Psi</u>
<u>Commercial</u>								
Westvaco Corp. ^{1/} (Tyrone, Pa.)	Aspen	Flake	43	3400	250	250	0.20	85
U.S. Plywood-Champion ^{1/} Papers, Inc. (Gaylord, Mich.)	Aspen core, pine face	Flake	28-43	2650	340	240	.14	90
Weyerhaeuser Co. ^{1/} (Marshfield, Wis.)	Aspen	Flake	42	2800	275	230	.18	85
Columbia Forest Products, Ltd. ^{1/} (Sprague, Manitoba)	Aspen- pine	Homogeneous flake	25-45	2500	300	250	.25	80
Waferboard Corp. ^{2/} (Timmings, Ontario)	Aspen	Wafer	40	3200	--	--	.12	60
<u>Laboratory</u>								
U.S. Forest Products Laboratory ^{3/} (Madison, Wis.)	Hybrid aspen clones	Flake	40	4500	--	--	.14	85

^{1/} Refer to Wood and Wood Products (1970).

^{2/} From a speech by Helmut Moeltner, DHYM, Ltd., New Liskead, Ont., presented at the Eastern Canadian Section, Forest Products Research Society Meeting, Thunder Bay, Ont., Oct. 1975.

^{3/} Unpublished data by Geimer.

Problems And Opportunities Associated With Aspen Logging Systems¹

Wendell H. Groff^{2/}

The opportunities in equipment selection, production ranges and specialization available to a logger producing volume from a coniferous species in many cases are not available to an aspen logger. The logger must identify the limiting factors and design a logging system accordingly.

The subject of harvesting aspen has long been of interest to both industry and the land management agencies in the Rocky Mountain Area. Industry, in many cases virtually starved for raw material, has viewed aspen as an alternative to the usual coniferous species as a resource base. The land management agencies, aware of the pressing need for forest products and the restraining effect of ever increasing land use restrictions, have looked upon aspen as a means of increasing the productivity of available forest lands both through managing lands with production of aspen as the objective and through harvesting aspen with the objective of fostering production of the coniferous species.

While aspen does present an opportunity in terms of available wood fiber, the nature of the species combined with the present state of development of the industries utilizing aspen as a raw material place serious limitations upon one who must design an efficient logging system to harvest aspen. Please note that a "logging system" includes all aspects of the operation needed to move useable logs from the standing trees to the processing facility. We must consider access roads, contractual requirements and value of end product as well as such normal logging activities as felling, skidding and so forth.

From the outset, we must remember that the industry in the Rocky Mountain Area is logging aspen in relatively limited quantities at the present time. Aspen trees make logs

and we know how to put logs into the mill. However, most aspen logging that I know of is being done with logging systems designed to produce logs from the coniferous species. In many cases this situation presents a problem in that the logging system in use is relatively inefficient when compared to one that could be designed to harvest aspen alone.

With the realization that present harvesting systems are successful to a degree in mind, the remainder of this report will present my own thoughts on why aspen is expensive to log in relation to the coniferous species and how these costs might be reduced.

Please note that I am speaking in very general terms. My comments are the result of my own experience with logging aspen in Southern Colorado and as such may not apply in other regions of the Rocky Mountain area.

General Remarks On Aspen As A Species

The aspen that I have worked with in the Rocky Mountains has really presented problems for the logger. It has been generally highly defective in terms of both visible and hidden rot, extremely crooked and of relatively small size. It seems that almost anything that can be wrong with a log will occur in aspen.

Aspen, when harvested for sawlogs, is commonly designated for cutting under one of three methods:

When aspen occurs in a mixed stand it may be individually tree marked to be cut along with the coniferous species.

In pure stands aspen may be designated for cutting on a diameter limit basis; a clear-cut if you will.

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, September 8-9, 1976.

^{2/} Southwest Forest Industries, South Fork, Colorado.

In a mixed stand with a manageable but sub-merchantable coniferous understory the aspen may be designated for cutting by over-wood removal to foster growth of the understory.

These methods of harvest have been mentioned to illustrate the different logging situations that the logger must be prepared to contend with. The point is that it is almost impossible to design a logging system that will operate with equal efficiency in all three cases.

Aspects Of Aspen Logging That Increase Cost

Please note that my comments are directed toward the present situation in the Rocky Mountain area. Problems such as these occur when aspen is harvested by logging systems designed to produce volume from the coniferous species.

In my mind, the problems associated with logging aspen fall into three broad categories.

I. Nature Of The Species

As I mentioned before, just about anything that can be wrong with a log will probably occur in aspen. This condition causes the work that must be done to produce a usable log to increase. Since per unit logging costs are simply a function of the amount of man and machine cost necessary to produce usable logs this increased work must result in higher unit costs. The loggers simply must do more work per unit of production.

II. Contractual Restrictions

This topic is of prime interest to land managers who are working toward a management objective. To the logger, contractual requirements will either increase or reduce the amount of work that he must do. The per unit costs of logging production will vary almost in direct proportion to the variation of work required.

Among the contractual requirements that have the most drastic effect on logging costs are:

Protection of residual stands when working with individual tree mark or over-wood removal harvesting systems. Required logging practices that cause higher logging costs are such things as longer skid distances, pulling winch lines further, restricting log lengths, and restricting number of chokers. All of these

restrictions may result in a loss in production per unit of time.

Slash treatment and/or disposal. The time that logging crews spend on slash treatment is time lost from actively producing logs. The more unproductive, in the sense of producing logs, work that they must do the more the per unit cost or production will rise.

High standard access roads may simply price the aspen logs involved out of the market.

Present utilization requirements specify that all sound wood that meets contractual specifications must be removed. This requirements causes real problems for a logger who must produce logs in eight foot multiples.

In my opinion, most of the problems that occur because of contractual restrictions are the result of applying a timber sale contract designed for a relatively high value species to low value aspen timber. In many cases the value of the end product to be derived from aspen logs will not cover the cost of producing those logs.

III. Economic Restrictions

The problems that fall under this category relate to the equipment choices available to the aspen logger and the opportunity for him to utilize that equipment in an efficient manner. Among the situations that are presently restricting the alternatives available to the logger are:

The mills currently utilizing aspen generally require a relatively small volume of wood annually. This means that a logger cannot really "gear up" for production unless he can work his men and equipment in other areas some of the time.

Relatively short operating seasons can further reduce the amount of time that the logging crews are working.

The value of aspen logs will many times not support high standard access roads. This can cause even more unproductive time as well as increased equipment repair cost.

These factors and others combine to effectively limit the time that an aspen logger actually spends producing logs. When one considers the effect of fixed cost and overhead it becomes apparent that per unit costs of production must go up unless the logger can produce at maximum efficiency.

Opportunities To Minimize The Cost Of Aspen Logging

Again let me emphasize that we are logging aspen right now. My comments are intended to present ways through which cost might be reduced in some situations. Careful planning of the logging operation, analysis of the logging situations to be encountered and cooperation between all organizations involved can at least minimize the effects of the restricting influences noted above.

Among the things that must be considered are:

I. Minimize The Effects Of The Nature Of The Species

Barring genetic development of a straight, sound aspen tree growing in a stand that produces 15,000 board feet per acre we can't do much about it.

II. Minimize The Effects Of Contractual Restrictions

The land managers must be aware of and practice the concept of "cost of log to mill". For the present time at least, it must be realized that perhaps the optimum level of land management cannot be achieved.

One possible way to reduce the cost of aspen logging would be to design a timber sale contract that recognizes the low value of the species and makes requirement of work accordingly. Within the value of the log, work and the associated cost elements should be allocated to the most desirable management objectives.

III. Minimize The Effects Of Economic Restrictions

The logger can do nothing about the nature of the species and very little about contractual restrictions. Further, short of moving to another area, he can do little if anything about the annual needs of the mill that he is working for.

However, through planning, analysis and initiative the logger can reduce his own logging cost by using the factors of production in the most efficient way available to him.

Among the ways through which the logger can improve the efficiency of his operation are:

If the mill needs only 2,000-3,000 MBF of aspen annually and there are no alternative means to utilize logging capacity then the logging system should be designed to produce only that amount. Among the things that should be considered are multi-use equipment such as self-loading log trucks, small crawler tractors, timber sales with primary access roads already in place and single species timber sales.

The logger should attempt to develop a market for all species of logs. This would allow him to extend the logging season, select single-use and more efficient equipment such as feller-bunchers and grapple skidders, work on mixed species timber sales and produce a higher volume annually.

All of these occurrences would have a favorable effect on logging costs.

The essential point is that the logger must be aware of the restricting influences under which he must work and design a logging system to fit a given situation. The equipment choices, production ranges and specialization available under conventional logging systems designed to produce logs from the coniferous species may simply not be available to an aspen logger. Therefore, he must either reduce his cost through proper equipment selection or increase his volume produced through developing a market for other species.

In this report I have tried to summarize my thoughts on and experience with aspen logging. In my experience it has generally been more expensive to log aspen than one of the coniferous species. I have been asked why many times and it always comes down to volume produced per unit of time. It appears to me that conventional logging systems, from standing tree to processing facility, have not produced aspen logs as efficiently as they might be.

The opportunity to reduce the cost of logging aspen does exist in certain areas, particularly those where multi-species utilization is the common practice. In these areas careful planning in scheduling operations and init-

iative in developing a market for logs from the coniferous species will allow the logger to operate more efficiently.

In conclusion, three points should be made:

The amount by which the "cost of log to mill" can be reduced through more efficient logging practices is relatively minor when compared to the reductions which can occur through elimination of certain contractual requirements.

The most efficient logging systems require heavy capital investment. I personally cannot foresee a prudent

logger making that investment unless he is assured of a long-term, high annual volume logging contract. At the present time it appears to me that these conditions cannot be met in the Rocky Mountain area.

The most potential for development of an efficient aspen logging system lies first with the land management agencies and secondly with industry in that high volume facilities must be developed.

Remember, the logger must have timber to log and he must have someplace to log it to.

Potential Utilization Of Aspen Residues In The Rocky Mountains¹

David P. Lowery^{2/}

Abstract.--The Rocky Mountain area has a good supply of aspen timber that is presently underutilized. The possibilities of utilizing logging residue and residue at primary manufacturing plants are explored. The pallet and container industries are potential markets for short board lengths. Short, clear, defect-free pieces of aspen can be used by furniture and toy manufacturers. Veneer waste also has value, as it can be processed into various consumer products.

INTRODUCTION

The aspen utilization problems of today in the Rocky Mountain area are essentially the same as those in Canada and are yesterday's problems in the Lake States. A symposium similar to this one was held in Edmonton, Alberta, in 1974 (Neilson and McBride 1974). The main problem for timber management in both Canada and the Rocky Mountain area is underutilization of the aspen resource and the main problem for the wood industry is how to utilize this species profitably.

Undoubtedly, the largest potential markets exist in primary manufacturing industries--pulp and paper, lumber, veneer and plywood, and particleboard. However, managers of primary manufacturing plants should be aware of other uses for aspen and thus be in a position to exploit these markets.

FOREST RESIDUES

For hardwoods such as aspen, forest residues are generally greater than for softwoods. This difference is due primarily to the crookedness of aspen stems, frequency of defects,

the relatively small size of the mature tree, and the tree's branching habit. To profitably utilize this species, which is normally converted into relatively low-value items, more complete utilization is required than for many of the western softwoods. A vertically integrated processing plant that could produce a primary commodity and secondary products would be ideal. Unfortunately, the scattered nature of aspen stands in this area precludes the establishment of an all-aspen complex. The goal, then, should be to completely utilize the material and to process the material into the highest value products possible.

In conventional harvesting operations, logs are bucked at the felling site and the tops and branches are left at this location for future disposal. But changes in harvesting operations are being made. Whole-tree chipping is becoming common. In the Northeast, more than 40 whole-tree chipping machines are in operation. Recent studies (Einspahr and Harper 1976) of this new harvesting system indicate that immediate increases in per-acre yield greater than 100 percent are obtained for hardwoods and 20 to 40 percent increases result for softwoods. In other words, conventional logging leaves approximately 50 percent of the aspen tree in the forest as residue at the time 50 percent is removed for manufacture.

A modification of whole-tree chipping that is being used in some areas is to skid the complete tree to a landing and there cut the stem into saw logs. The tree crown is then chipped. Both whole-tree chipping and whole-tree skidding have the advantage of leaving the harvested area clean and esthetically pleasing. Most of the chips from these newer harvesting methods

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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are suitable for use by the pulp and paper industry and the remainder can be used as fuel. The residue from conventional harvesting also has value as firewood.

FUEL POSSIBILITIES

The increasingly high cost of energy derived from fossil fuels is making the burning of wood in homes, resorts, and wood processing plants more feasible. It also is contributing to higher prices for fuelwood. Last winter in some areas of Utah, firewood was selling for about \$60 per cord.

The fuel value of aspen is the same as that of practically all wood--approximately 8,000 Btu's per pound of dry wood. The specific gravity of aspen, 0.35, means that a greater amount of wood is required to weigh a pound in comparison with some of the denser eastern hardwoods such as oak, hickory, birch, and maple. The specific gravity of aspen is slightly greater than that of Engelmann spruce and slightly less than that of lodgepole pine. Two pounds of dry aspen wood has approximately the same heating value as a pound of coal, and about two cords of air-dry aspen is equivalent to a ton of coal.

Table 1 summarizes some of the pertinent values for aspen fuelwood:

Table 1.--Values important to use of wood species for fuel, for green and air-dry aspen (from Panshin and others 1950)

Weight/cord : (pounds)		Heat content : (million Btu):		Equivalent in tons of coal	
Green	Air-dry	Green	Air-dry	Green	Air-dry
3,440	2,160	10.3	12.5	0.47	0.57

The data in table 1 emphasize the importance of burning only well-seasoned or dry wood. If the wood is green or wet, it not only does not burn well, but a large amount of the heat generated in burning is used to evaporate the moisture present, so that combustion can continue. Storing and piling large quantities of wood also can pose problems.

USE AS PRODUCT STOCK

Residue at primary manufacturing plants also has considerable value. Short board lengths produced from crooked logs by the sawmill are often suitable for pallets, boxes, crates, and various small items. The charac-

teristics of aspen that make it desirable for pallets and containers are its straightness of grain, ease of nailing, relatively light weight, and ease of stamping or branding.

The pallet industry is one of the fastest growing segments of the wood products industry. From practically nothing 20 years ago, the industry growth has been so great that today the National Pallet and Container Association estimates that one of every four trees felled in this country is used in pallet or box construction. The growth of the industry is expected to continue in future years.

There are several different types of pallets, classified according to their use. The two most common types are the standard or general purpose pallet used for storage and shipment of various items such as groceries and hardware and the bin or box pallet often used in orchards for transporting picked fruit. The standard pallet is 40 by 48 inches and contains approximately 26 board feet of lumber. In 1973, more than 200 million of these pallets were assembled (Reeves 1974). The bin pallet is the same size and of similar construction, but it has a plywood box attached to the pallet base. A much smaller number of bin pallets is required annually.

The general purpose pallet consists of stringers, leadboards, and centerboards. Stringers separate the top and bottom decks; leadboards are located on the edges and take most of the abuse from the forklift trucks; and centerboards provide the bearing surface that supports the load. The strength properties and other characteristics of aspen would ordinarily restrict its use to centerboards, but suitable designs and nailing patterns have been developed for all-aspen pallets (Heebink 1962; Stern 1974, 1975). All-aspen pallets are lighter and stiffer, but somewhat less rigid, than comparable all-oak pallets.

Preassembled pallets are bulky and costly to ship long distances, but pallet parts can be shipped relatively long distances for assembly by a dealer or user.

The same characteristics that make aspen suitable for pallet manufacture also make the species suitable for box and crate construction. Although many fruits and vegetables are now being shipped in fiberboard boxes and the use of box shooks has been decreasing, the market is still sizable. The fruit-growing areas of the Southwest and Utah should be able to use aspen boxes. Mill managers considering such an outlet should study the situation carefully before embarking on the required investment or expansion program.

Aspen is also suitable for the manufacture of grain doors used in railroad cars during the shipment of wheat and other cereals. The wood is tasteless and odorless when dry and thus would not contaminate the cargo.

Other options are available for the sawmills that produce considerable quantities of aspen. Because aspen is a preferred species in the toy, furniture, and door industries, a "cut-up" operation may be a profitable venture. Such an operation would produce small, clear, defect-free pieces by ripping and crosscutting long and short boards to the desired sizes. Light weight and favorable fastening, machining, finishing, and gluing characteristics make aspen an ideal wood for various remanufacturing industries including those mentioned.

Toy manufacturers often use aspen for cut-outs and play furniture. Furniture producers use aspen for parts and lumber core stock to be overlaid with decorative veneer. Glued-up aspen blanks are covered with plywood skins in the manufacture of solid-core doors and individual pieces may be used as spacers and the framing for hollow-core doors.

Aspen veneer waste at plywood mills can often be processed into small wood items such as tongue depressors, ice cream and popsicle sticks, swizzle sticks, toothpicks, sticks for cotton swabs, and matchsticks. The species is an excellent wood for these uses because of its light weight, light color, and lack of taste.

CONCLUSIONS

The potential for utilizing aspen boards and residue from primary manufacturing plants is tremendous. The desirable characteristics of the species make it suitable for many diverse uses.

Sawmill waste can be chipped to provide raw material for the pulp and paper and particleboard industry. However, this same residue can often be processed into stock for secondary manufacture. The only limitations on aspen use are the time, effort, and capital industry management is willing to devote to it.

LITERATURE CITED

- Einspahr, W. E., and Marianne Harper.
1976. Hardwood bark properties important to the manufacture of fiber products. For. Prod. J. 26(6):28-31.
- Heebink, T. B.
1962. Performance of pallets from low-quality aspen. For. Prod. Lab. Rep. No. 2264. For. Prod. Lab., Madison, Wisc.
- Neilson, R. W., and C. F. McBride.
1974. Poplar utilization symposium proceedings. Inf. Rep. VP-X-127. Can. West. For. Prod. Lab., Vancouver, B.C.
- Panshin, A. J., E. S. Harrar, W. J. Baker, and P. B. Proctor.
1950. Forest products, their sources, production and utilization. McGraw-Hill Book Co., New York, N.Y.
- Reeves, J. R.
1974. The potential of poplar for pallets. Poplar utilization symposium proceedings. Inf. Rep. VP-X-127. Can. For. Prod. Lab., Vancouver, B.C.
- Stern, George E.
1974. Design of pallet deckboard--stringer joints, Pt. 1: aspen pallet joints and aspen pallets. Va. Polytech. Inst. and State Univ. Bull. 126, Blacksburg, Va.
- Stern, George E.
1975. Design of pallet deckboard--stringer joints, Pt. 2: reinforced aspen pallet joints and aspen pallets. Va. Polytech. Inst. and State Univ. Bull. 133, Blacksburg, Va.

Recommendations On Processing And Storage Of Aspen Residue¹

Andrew J. Baker^{2/}

Physical properties of residues of aspen wood and bark are summarized as are the processing requirements for marketing residues of the bark and wood for fuel, mulch, and poultry bedding at a primary manufacturing plant.

Important considerations in marketing and using residue of aspen wood and bark are processing methods and storage. The end-use requirements of the residue will determine processing needs and will also dictate storage conditions that can be tolerated. This report will summarize the physical properties of aspen wood and bark residue and the processing and storage requirements to market aspen wood and residue for fuel, mulch, and animal and poultry bedding at a primary manufacturing plant.

PROPERTIES OF ASPEN RESIDUE

For information on the physical properties of midwestern wood and bark residues and the processing required to make them acceptable for various markets, McGovern (1976)^{3/} collected samples of various residues and noted moisture content and bulk density before and after additional processing. Table 1 contains that information for aspen residue. The bark residue was in a form satisfactory only for fuel, but the sawdust and pulp chip screener fines were suitable for animal bedding in addition to fuel.

^{1/} Presented at Symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colo., Sept. 8-9, 1976.

^{2/} Chemical Engineer, U.S. Dept. of Agric., For. Serv., For. Prod. Lab., Madison, Wis. 53705. The Laboratory is maintained at Madison in co-operation with the University of Wisconsin.

^{3/} McGovern, J. N., C. E. Zehner, and J. B. Boyle. 1976. Investigations of Bark Residue for Livestock Bedding. For. Prod. J. (In press).

RESIDUE PROCESSING

To make bark acceptable as an animal bedding or mulch, McGovern processed bark in various ways (table 2). The barks referred to as having well-reduced particles were considered **suitable** for animal bedding or mulch. Hammermilled aspen bark was determined an excellent dairy cow bedding in tests at the University of Wisconsin-Madison. He noted, for bedding, a certain amount of fines in the fibrous bark aids in forming a bed, or mat, on concrete in an animal stall. The amount of bedding required per animal was greater with processed bark than with straw because of the differences in bulk density, but when considering its use, the total cost and availability must also be considered. For bedding, the bark should be in the green condition. When green, there is no dust problem and the bark forms a more stable mat than does straw. Aspen bark absorbs barn odors; this quality plus the others makes it a desirable animal bedding.

Aspen bark that is acceptable for animal bedding also is an acceptable mulch. Again the presence of a certain amount of fines is desirable, and the bark should be used in the green condition.

For poultry bedding, the bark must be dry to avoid health problems and the fines must be removed to avoid dust. Highly fibrous, bulky material is not desirable for poultry bedding.

STORAGE

Aspen bark has accumulated in piles at many Lake States mills. The piles constitute a hazard because the bark leaches and can burn. Little has been done to determine the effects of the leachate. Under certain circumstances,

the leachate could be a problem because it will probably be colored with water-soluble extrac-tives and may contain biological and thermal degradation products of wood and bark.

The storage of aspen pulp chips, aspen bark, and aspen whole-tree chips has been investigated at the Forest Products Laboratory; estimates at the Laboratory showed that outside stored aspen pulp chips lose about 1 percent weight per month due to biological degradation. In work at the Laboratory by Zoch on the storage of aspen bark, he constructed a 40- by 40- by 20-foot-high aspen bark pile in which thermocouples and weighed samples were placed. Preliminary results indicate the pile reached internal temperatures higher than 150° F. during the first 3 weeks of storage. The bark and the nylon mesh bags containing weighed samples within the pile in the high-temperature area were severely degraded after 1 year. Estimated weight loss during the

year was 10 to 18 percent. Whole-tree chips are very susceptible to biological degradation. In experimental storage conditions at the Lab-oratory, rapid temperature increases have been observed. Where whole-tree chips are harvested and utilized, they usually are not allowed to accumulate. Users of whole-tree chips have reported that a pile can become warm or hot to the touch overnight.

The recommendation for storage of chips, if storage is necessary for more than 1 or 2 weeks, is the pile should not be built higher than about 20 feet. For bark storage, the pile should be only 10 to 15 feet high. Whole-tree chips intended for use as wood fiber should not be stored. Storage should usually not be on the ground because dirt will be picked up when the stored material is recovered. Even if chips are used as fuel, the soil and rocks can be a serious problem.

Table 1.--Properties of Aspen Residue^{1/}

Aspen Residue	Debarker	Processing Equipment	Moisture ^{2/}	Bulk Density ^{3/}	Applications
			Pct	Lb/ft ³	
Bark	Rosser, ring	None	33-47	7.9-16.4	Landfill
Bark	Rosser, ring	Hog, hammer-mill	45-47	9.1-10.4	Fuel, incinerate, landfill
Sawdust	--	Circular saw, edger	40-55	4.8-7.2	Bedding, fuel, products, incinerate, landfill
Pulp chip screener fines	--	Screen	51	8.6	Bedding, pulping, fuel, incinerate, landfill

^{1/} McGovern, J. N., C. E. Zehner, and J. B. Boyle. 1976. Investigations of Bark Residue for Livestock Bedding. For. Prod. J. (In press).

^{2/} Green basis.

^{3/} Ovendry weight per green volume.

Table 2.--Properties of Processed Aspen Barks^{1/}

Material	Processing	Fines Content	Bulk Density ^{2/}			Particle Nature
			Fines	Coarse	Aggregate	
		Pct		Lb/ft ³		
<u>Aspen bark</u>						
Ring debarked	Shredded-coarse	10.2	18.5	13.1	14.2	Coarse; unusable
Ring debarked	Shredded fine	23.8	16.8	10.1	10.6	Coarse; unusable
Shredded coarse	Hammermill-1 ^{3/}	45.3	24.8	12.3	15.2	Well reduced
Shredded coarse	Hammermill-2 ^{3/}	48.4	17.6	8.0	11.5	Well reduced
Ring debarked	Hammermill ^{4/}	34.5	13.7	--	10.1	Well reduced
Shredded coarse	Disk refiner- atmospheric	66.4	20.2	3.4	8.6	Well reduced
Shredded coarse	Disk refiner- pressure	28.7	--	--	3.2	Fibrous
<u>Commercial bedding</u>						
Wood shavings	--	20.9	--	--	6.0	--
Oat straw	--	--	--	--	1.2	--

^{1/} McGovern J. N., C. E. Zehner, and J. B. Boyle. 1976. Investigations of Bark Residue for Livestock Bedding. For. Prod. J. (In press).

^{2/} Dry weight per green volume.

^{3/} Fixed hammer.

^{4/} Swing hammer.

Panel V.
Applying Research Information
To Aspen Management Decisions

Moderator: John E. Bennett

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Applying Research Information To Aspen Management Decisions — National Forests¹

David L. Hessel ²/_—

Abstract.--Aspen management on the National Forests of the Rocky Mountains has been at a very low level. Decisions on how this valuable resource is to be managed in the future to meet multiple use goals must be based on the best research information available. Land allocations made through the land use planning process (including NEPA) will define land management objectives for the aspen type. The choice of treatment of the aspen type depends upon the multiple-use objectives and local ecological conditions.

Past and Present Aspen Management

Colorado, as well as other states in the Rocky Mountains, is nationally known for its scenic beauty and recreation opportunities. The mountains and forests of these states draw millions of tourists to them each year. The aspen within these forests, of all the tree species in the Rocky Mountains, offers the greatest contrasts in scenic qualities. The green leaves mixed with white bark and then the fall colors of reds and golds combine to make forests of outstanding scenic beauty.

The aspen type on many National Forests also provides forage for livestock to produce red meat for the Nation. It is also key habitat for many species of wildlife.

In the past 70 plus years of National Forest management, the four million acres of aspen commercial forest lands have received little silvicultural treatment.

Also, in the past 50 years, fire has generally been controlled and kept out of the National Forests. With the past history of management, what is happening to many aspen stands in the Rocky Mountains?

¹/_— Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Fort Collins, Colorado, Sept. 8-9, 1976.

²/_— Timber Management, USDA Forest Service, Region 2, Lakewood, Colorado.

Natural Succession

Aspen is being and will eventually be replaced in the Rocky Mountains by spruce and fir. Also, stands are over-mature and falling apart, losing fiber production.

Is this what is best for the National Forests in the Rocky Mountains to provide the American public its needs now and in the future?

Aspen Management Objectives

Aspen, as well as other resources of the National Forests, are managed to meet multiple use goals. Consideration must be given aspen timber values, other timber species values, wildlife habitat, recreation, range, esthetics, watershed and environment protection. It is important that the Forest Service keep in tune with the changing world in which we live. Making sure we are responsive and alert to the changing needs of a dynamic society requires a continuing evaluation of our management objectives and policies.

Some broad objectives that we must consider in managing aspen are:

1. To promote and achieve a pattern of natural resource use that will best meet the needs of people now and in the future.
2. To protect and improve the quality of air, water, soil, range, wildlife habitat, recreation and natural beauty.

3. To generate forestry-based job opportunity to accelerate rural community growth.

4. To encourage the growth and development of forestry-based enterprises that readily respond to consumer's changing needs.

5. To develop and make available a firm scientific base for the advancement of forestry.

In order to meet these broad objectives, we must fit the aspen lands into the total resource and environmental picture. We have considered that change or modification is not strictly a timber production option. Moreover, a choice of action is not based on simple rules and it cannot be made for any single stand of timber in isolation from the surrounding land and human developments.

Multiple-use management explicitly recognizes the "jointness" of forestry in the sense that whatever we do to the forest environment is likely to affect the level and quality of more than one of the several "products" of the forest. These products are valued in several ways, not only in terms of dollars, but also in terms of less easily quantified values such as esthetics. Regardless of the values used, questions arise regarding the efficient allocation of forest and other resources to the production of these various products.

To be more specific, the principal potential uses of lands now occupied by aspen stands are:

Wildlife

The vegetation is used as a food and cover type. Some aspen provides big game winter range, but mostly is spring, summer, and fall range. The type is important for elk, deer, black bear, beaver, woodpeckers, the flammulated owl, and other species of nongame animals and birds. A key element in the management of the aspen type is the need for an appropriate mixture, in both area and distribution of aspen and conifer types, to assure a complete habitat for wildlife.

Watershed Protection

Aspen is valuable as protective watershed cover because of its rapid initial height growth characteristics and extensive lateral root system.

Recreation

Aspen adds to the recreation use in several ways. Maintenance of aspen ecosystem adds variety to the forest in terms of the diversity and number of species of wildlife available for viewing and studying. Large monocultures of ponderosa pine, lodgepole pine, and spruce are disrupted and vegetative variety is maintained or can be introduced.

Scenery

Aspen is an important tool to maintain or introduce color form and texture in landscape management in the Rocky Mountains. Color contrast, especially in the spring and autumn, is a highly valued resource of the Rocky Mountains.

Fire Management

Aspen has different burning properties than conifer stands. An appropriately designed pattern of aspen stands within larger areas of conifer stands could serve as a living fire break while serving other important management needs.

Grazing of Domestic Livestock

The understories (shrubs, grasses, and forbs) of aspen stands provide a great deal of forage used by cattle and sheep. Herbaceous production usually exceeds 1,000 pounds per acre on the most productive sites.

Wood and Fiber Production

Current utilization of aspen stands is 5-10 million board feet in Region 2. The potential is significant as aspen is suitable for core stock, studs, veneer, panels, lumber, pulp, excelsior, and possibly as a livestock and wildlife food supplement.

In light of the multiple-use concepts, and the broad management objectives and the specific potentials for the aspen type, land allocation decisions must be made through land-use planning including the NEPA process. The decision for aspen lands must be based on research information as is being assembled, presented, and discussed at this symposium.

Applying Research Information to

Aspen Management Decisions

As stated earlier in the session, the National Forests of the Rocky Mountains have over 4 million acres of commercial aspen forest lands that are capable of producing 20 cubic ft./acre/year. Land management decisions must be made on these acres. To accomplish the management objective, I see there are basically three options of treatment: regenerate aspen, allow natural conversion to another type, or artificially reforest. These choices depend on the multiple-use objective.

Therefore, the land manager has three harvest alternatives to consider in aspen management: clearcut, partial cut, or do nothing.

In the past it has been the response to these harvest alternatives in the Rocky Mountains to place the aspen in the unregulated components. Treatment by clearcutting or shelterwood led, in some instances, to suckering so profuse that it caused total site occupancy. This in turn eliminates the understory herbaceous vegetation critical to wildlife and domestic livestock needs.

In some instances in Region 2, suckering has not occurred, indicating that elements critical to the reproductive process have not

been properly identified and handled. These elements must be identified and appropriate prescriptions developed to assure they are properly considered. The interaction of soil types and climatic conditions as they relate to the reproduction processes are not entirely defined.

The basic problem in Region 2 is that more information is needed on aspen management so that we can regulate aspen in our timber management plans, thus realizing its full potential.

Research studies and information as presented here at this symposium will help form the basis for the land manager to make decisions in the land-use planning process. It is these decisions that will result in the eventual establishment of potential yields from the aspen stands in the National Forest Timber Management Plans. I see this as a prerequisite in order to attract industry. Any industry must know its raw material supply; without a market for the wood fiber, little management will be accomplished.

Aspen in the Rocky Mountains can be elevated from its non-use status of recent years through advanced technology in its utilization as a wood fiber and development of a research base required to apply silvicultural techniques to achieve the desired management responses.

Guidelines For Aspen Management¹

David R. Betters²/

Abstract.--The aspen of the Rocky Mountain Region represents a large, diverse resource. Currently there are no specific, detailed guidelines for its management. The development of management guidelines requires, in part, the identification of aspen's possible uses, stand-site characteristics to meet those uses and silvicultural prescriptions.

Guidelines, based on stand-site suitability, were developed and applied to a planning unit on the Routt National Forest of Colorado. The application, although limited in scope, did indicate the guidelines could be useful to aid in determining what aspen sites were most suitable for certain uses and what management alternatives might be applicable.

There are an estimated 3 million acres of aspen type forests in the Rocky Mountain Region. These forests have the potential to provide a wide range of possible uses. However, at the present time there are no specific, detailed guidelines for their management.

An approach to developing such guidelines should include:

- 1) Identifying and describing the uses for which aspen stands can be managed.
- 2) Identifying and describing the aspen stand characteristics most suitable to meet those uses.
- 3) Identifying and describing the possible management prescriptions given use and stand-site conditions.
- 4) Constructing a procedure to define aspen stand suitability for various uses.

USES

Aspen stands, when compared with most other forest types, provide an extremely wide range of possible uses. In the Central Rocky Mountains aspen timberlands serve for such significant uses as: wildlife habitat,

domestic livestock range, raw material for wood production, watershed protection, water production, scenery and firebreaks.

These are certainly not minor but major values since aspen is very well suited for these uses. For example, in the case of wildlife habitat, aspen is the number one big game browse species and an important elk calving area (Jones 1974). Further it provides food and cover for a number of small wildlife species including grouse and the beaver (Beetle 1974).

Its value as domestic livestock range is exemplified by the fact that aspen typically produces six times the forage as adjacent conifer stands (Reynolds 1969). Most pure aspen stands have a heavy understory of various grasses and forbs which provide summer grazing for sheep and cattle.

As a wood raw material in the Central Rockies it is presently used to manufacture pallets, paneling and numerous specialty products (Wengert 1976).³/ Although its high moisture content, decay and small size cause problems the opportunities for expanding this type production along with its use for fence poles, livestock bedding and feed seem to be significant. In particular, livestock feed possibilities have been recently explored by a number of researchers (Milligan 1974).

¹/ Paper presented at the symposium Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Fort Collins, Colorado, Sept. 8-9, 1976.

²/ Assistant Professor, Department of Forest and Wood Sciences, Colorado State University, Fort Collins, Colorado.

³/ E. M. Wengert, Final report, aspen wood utilization in the Rocky Mountains, Work Unit FS-RM-4351, USDA Forest Service, Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colorado, 1976.

Aspen provides an important watershed protection role through its extensive lateral root system. Even one tree can provide considerable protection from erosion. It sprouts prolifically and quickly thus minimizing the time the site is bare (Croft and Monninger 1952). The fact that it often occurs on moist sites serves to further emphasize the significance of this use.

In comparison with other forest types aspen sites generate more water for runoff. Aspen typically has higher water yields than conifer stands in the snowpack zone (Dunford 1944, Hoff 1957). This occurs because aspen has less interception losses and a faster snowmelt period allowing more water for overland flow.

The beauty of aspen stands in the Fall is well known to those familiar with the Central Rockies. There is really no way to accurately measure the importance of this esthetic appeal. The stands intermingle with the darker conifers in a myriad of forms adding an especially appealing color and texture to the landscape.

Finally, aspen is an excellent firebreak in that it has little dead fuels and no ladder fuels to carry a fire to the crown (Fechner and Barrows 1976). In many cases, fires have been "herded" into aspen stands to control conflagrations. Aspen clumps are particularly valuable where they mix with conifers and occur along roads, ridgetops or the bases of slopes where firelines might be constructed for fire control.

STAND-SITE CHARACTERISTICS

The stand-site conditions of Central Rocky Mountain aspen are very complex and diverse. It's been said that aspen has the most unique and variable characteristics of any North American tree species (Smith 1962). For example, it has a wide altitudinal range, has many different herbaceous understories, mixes with several coniferous species, grows in clones and has many stand structures ranging from all-aged to even-aged. Further, it occurs on several different soil types and various visual zones. This variety typifies the species and causes some management difficulties as well as opportunities.

The clones of aspen have different genetic characteristics which develop varying growth rates, sprouting characteristics, disease susceptibility and tree form. Because of clonal differences the same site conditions may have vastly different stand qualities. Whether there are only 2 or 3

clones or many is presently unknown. Obviously timber stand improvement work has major possibilities in the management of this resource.

These varying clonal characteristics, in part, contribute to the unpredictability of aspen sprouting. In some cases stands will deteriorate naturally and no sprouting will occur (Schier 1975). In other situations it sprouts under the deteriorating overstory (Jones and Harper 1976).^{4/} Cutting in certain areas generates prolific sprouting in others none at all. In some instances aspen will invade adjacent grassland, in others it maintains a static border. Of course, the inability to predict sprouting is a major management problem.

The insect and disease attacks in aspen are significant. In the Central Rockies Cytospora, black and sooty bark cankers along with insect defoliators and borers cause considerable damage (Hinds 1964). Many older stands, after age 80, have appreciable amounts of defect and decay. Before age 80 most stands have a much lower percentage of rot (Davidson et al. 1959). This, of course, has a tremendous impact on the suitability of the wood for wood products and further affects the esthetic appeal of the resource.

The species mixes with conifers and many areas exhibit varying levels of succession. At first, the aspen acts as a "nurse crop" while the conifers become established in the understory. Then, as time goes on, the conifers and aspen mix as mature trees in the overstory until eventually the aspen is completely overtopped and dies (Weigle and Frothingham 1911). Where a conifer seed source exists this is the typical successional process.

Aspen also occurs with sagebrush, brush, grass and/or forbs. It can occur with understories of grass, grass/forbs, tall forbs or brush. In some cases these pure aspen stands deteriorate and convert to sagebrush, brush or grass--particularly at the lower elevations. In other areas, under certain conditions, it seems to perpetuate itself. These areas ought to remain aspen for some time and have been identified by several investigators as aspen climax zones (Baker 1925, Beetle 1974).

^{4/} John R. Jones and Kimball T. Harper, Unpublished Draft Manuscript 1203.47 Aspen Ecology and Management in the Western United States.

Regarding aspen sites Reed (1971) states that the only common factor is that they occur on mineral soils. The better, more productive sites, however, are typically moister soils with a high organic matter content (Tew 1968). The best soils are loams, silty loams or clay loams derived from drifts that have a limey substrate (Brinkman and Roe 1975). Any appreciable amount of rock or gravel creates a poorer site as this interferes with the species lateral root development.

SILVICULTURAL PRESCRIPTIONS

There are many silvicultural prescriptions possible for aspen stands. These prescriptions may vary by use objectives and stand-site conditions.

The best harvesting method is to either clearcut or use a heavy selection with either tree length or shortwood logging (Heinselman 1966, Zasada 1972). Partial harvests are acceptable if at least 60 to 70% of the basal area is removed--otherwise the number and form of the sprouts is affected (Smith 1962). Cutting ought to be done in the best clones to perpetuate those genetically superior traits.

The best rotation age for the better sites has been found to be 70 or 80 years (Millar 1974). Thins can be scheduled between 5 to 15 years of age. It's best to wait at least 5 years as natural competition will remove several of the sprouts (Jones 1976). At the other extreme 15 years is a limit in that cutting done later might stimulate new suckers as the sprouts have developed their own root systems.

Chemical treatments can be used to thin stands. Chemicals including sodium arsenite, 2-4-5T and 2-4D are effective (Johnston 1969). If chemicals or cutting is not feasible heavy grazing by sheep two or three years following cutting will also eliminate sprouts (Baker 1925).

Where a conifer understory exists and conifers are desired care must be taken to insure the conifer understory is well established before any cutting of the aspen takes place. Otherwise the chances are that the site will be taken over by aspen for some time (Jones 1974). Even scattered aspen within a conifer stand can develop significant amounts of sprouting if the forest floor is opened up to sunlight.

Prescribed burns can also be used to stimulate sprouting and/or remove an aspen overstory. However it should be noted that only under certain conditions will the fire resistant aspen carry a fire.

These prescriptions typically benefit many uses in providing increased wildlife browse, livestock forage and water runoff. The treatments also help perpetuate the aspen for scenic purposes and watershed-firebreak protection.

GUIDELINES

In order to develop a management approach the variety of stand-site conditions must be depicted in a classification scheme. As a first step the most important characteristics concerning the conditions need to be identified for the aspen resource. These characteristics should be those considered to be necessary to determine the area's suitability for aspen's large number of uses. They should be those characteristics easily identifiable in the field and be available in present inventories. Further, they ought to include criterion, such as visual zoning, which is not a vegetative descriptor but is an important factor to consider in making management decisions. The criteria should be capable of describing the large variability in the resource. Although others might be considered a set of characteristics could include:

- 1) soil stability
- 2) aspen vegetative type (i.e. aspen/
grass, etc.)
- 3) timber site quality
- 4) scenic rating (partial retention, etc.)
- 5) stand structure

The suitability of an aspen site can be determined using these characteristics. A procedure to link site condition to its most suitable uses would involve two steps. First, the characteristics, 1 through 5, must be ranked as to their importance for each use. For example, what characteristics are most important for determining an aspen site's suitability for timber use? Second, given a particular use, the favorable and unfavorable conditions for each characteristic must be identified. Table 1 illustrates this approach using timber production as an example.

This same procedure might be used to determine the characteristic importance rankings and condition favorability for the number of different uses of aspen. These rankings and conditions may be quite distinct for each

Table 1.--An example of determining characteristic importance and condition favorability for timber use.

Aspen Characteristic Importance Ranking	Conditions of Favorability	
	Favorable	Less Favorable
#1 Timber Site Quality	I-II	III-V ^{1/}
#2 Soil Stability	Stable; Mod. Stable	Unstable ^{2/}
#3 Scenic Rating	Mod./Max. Mod.	PR-Ret. ^{3/}
#4 Vegetative Type	Pure aspen w/ herbaceous understory	Aspen mixed with conifer ^{4/}
#5 Stand Structure	Undiff.	^{5/}

^{1/} Baker (1925) aspen site index.

^{2/} As defined in unit land use plans.

^{3/} As defined in USDA USFS Handbook #434.

^{4/} As defined in unit land use plans.

^{5/} Undifferentiated--meaning any condition is equally favorable.

use. For example, timber site quality may be very important in determining timber suitability (#1) but be of little consequence for forage rankings (#4). A timber quality index of I or II might be a favorable condition for timber but any index might be equally favorable for forage. These type differences exist for all uses.

By numerically weighting each characteristic in order of importance, individual use ratings can be developed for an aspen site. For example, using this approach an aspen site having moderately stable soils, a timber site quality of I, an aspen/grass vegetative type and a partial retention scenic zoning was rated 8 for timber, 8 for forage and 10 for scenery (out of a possible 10). Other uses were rated much lower. Thus this site is most suitable for timber, forage and scenery uses.

APPLICATION

This approach was developed and applied in a summer study of the aspen resource on the Routt National Forest in Colorado (Betters 1976). In forming the importance rankings and conditions for favorability various forest managers were consulted for their opinions. What finally developed was a set of keys similar to taxonomic keys which could be easily used to determine a site's suitability for various uses. As a final step a set of management alternatives was then offered given an area's overall suitability rankings.

In field testing the guidelines it was obvious that numerous aspen sites were very suitable for many uses. Several areas on the

Routt National Forest were highly suited for timber-forage-scenery uses. Many other sites were very suitable for watershed protection, scenery and firebreaks. The prescriptions for each use are essentially the same. These numerous complementary, noncompetitive relationships indicate significant possibilities for multiple use management.

This does have major importance in the development of an aspen management program. For instance, prescriptions may not be justified solely on the basis of timber value but on multi-use sites, considering all uses, the total benefits may far outweigh the costs. Wood utilization markets now plague the development of a management program. However, if all the uses are considered, there may be ample justification for prescriptions through joint funding means. The timber value may be low but when all values are considered the total may be quite high. The resource represents a real opportunity for integrated multiple use management as emphasized in several major legislative acts of the last fifteen years.

CONCLUSIONS

Although the application of the guidelines was limited in scope, it did indicate that they could be useful to determine:

- 1) what uses the aspen has in an area.
- 2) where the areas are located that are most suitable for certain uses and how they are described.
- 3) what alternatives may be applied to these areas given suitability for certain uses.

The approach has further merit in that it necessitates describing which characteristics are important to determining uses. This, in itself, is an exercise which benefits the manager's decision making process. What may have been a subjective process before now follows a clear pattern and allows easy communication of one's views. There may be disagreement as to what factors are most important to determining the suitability of aspen for various uses. This approach provides a format for discussion of these very important points. Further, the format, that of describing uses, stand-site characteristics and prescriptions provides an excellent means of consolidating research information. It is a logical separation of key areas which facilitates the dissemination of research results for field application.

In answering the question, "How do we manage the aspen?" the aspects studied here must be coupled with the total resource management situation. Aspen management direction can only be developed through systematic consideration of all the natural resources, demands and multiple goals for the entire unit, forest or region. The information provided by this approach can play a significant role in constructing these integrated resource management plans.

The aspen represents a tremendous resource capable of generating significant multiple benefits. Its management requires the application of research results in several key areas. Certainly those mentioned--uses, stand-site characteristics and prescriptions--need continuing work to increase our knowledge of the resource. The future management of the aspen will rely on the application of these results to help provide for selecting the best management program.

LITERATURE CITED

- Baker, Fredrick S.
1925. Aspen in the Central Rocky Mountain Region, USDA Department Bulletin #1291. 47 p.
- Beetle, A. A.
1974. Range Survey in Teton Country, Wyoming, Part IV--Quaking Aspen, Agric. Exp. Station, Univ. of Wyoming, Ser 27. 28 p.
- Betters, D. R.
1976. The aspen, guidelines for decision making, USDA Forest Service, Routt National Forest. 100 p.
- Brinkman, Kenneth A. and Eugene I. Roe.
1975. Quaking aspen: Silvics and management in the U. S., Agric. Handbook #486. 52 p.
- Croft, A. R. and L. V. Monninger.
1953. Evapotranspiration and other water losses on some aspen forest types in relation to water available for stream flow, Transactions, American Geophysical Union, Vol 34, No. 4.
- Davidson, R. W., T. E. Hinds and H. E. Hawksworth.
1959. Decay of aspen in Colorado, USDA Forest Service, Rocky Mt. For. and Range Exp. Station, Station Paper #45. 14 p.
- Fechner, G. H. and J. S. Barrows.
1976. Aspen stands as wildfire fuel breaks, USDA Forest Service, Eisenhower Consortium Bull. 4. 26 p.
- Heinselman, M. L.
1966. Trends in natural succession in the aspen type, USDA Forest Service, Lake States For. Exp. Stat., Silviculture of Northern Conifers and Aspen Project.
- Hinds, T. E.
1964. Distribution of aspen cankers in Colorado, Plant Disease Reporter, Vol 28, #8, pp. 610-614.
- Hoff, C. Clayton.
1957. A comparison of soil, climate, and rotation of conifer and aspen communities in the Central Rocky Mountains, The American Midland Naturalist, Vol 58, pp. 115-140.
- Johnston, R. S.
1969. Aspen sprout production and water use, USDA Forest Service Research Note INT-89. 6 p.
- Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen, USDA Forest Service, Research Paper RM-122. 44 p.
- Millar, M. C.
1974. Poplar management in Saskatchewan, VP-127, Poplar Utilization Symposium, Canadian Forest Service. pp. 43-50.
- Milligan, J. D.
1974. The use of aspen in livestock feed, VP-127, Poplar Utilization Symposium, Canadian Forest Service. pp. 196-205.
- Reed, R. M.
1971. Aspen forest of the Wind River Mountains Wyoming, The American Midlands Naturalist, 86(2). pp. 327-343.
- Reynolds, Hudson G.
1966. Use of opening in spruce-fir forest of Arizona by elk, deer, and cattle, USDA Forest Service, Res. Note RM-66. 4 p.
- Schier, G. A.
1975. Deterioration of aspen clones in the Middle Rocky Mountains, USDA Forest Service Research Paper INT-1970. 14 p.
- Smith, David.
1962. The practice of silviculture, Seventh Edition, John Miller and Sons, Inc., New York. 578 p.

Tew, Ronald.

1968. Properties of soil under aspen and herb-shrub cover, USDA Forest Service, Res. Note INT-78. 4 p.

Weigle, W. G. and E. H. Frothingham.

1911. The aspens: Their growth and management, USDA Forest Service, Bulletin 93. 34 p.

Zasada, Z. A.

1972. Mechanized harvesting systems can aid management. In: Aspen Symposium Proceedings, USDA Forest Service Technical Report NC-1. pp 131-136.

Applying Research Information To Aspen Management Decisions— State And Private Lands¹

Thomas J. Loring^{2/}

Abstract.--Any management decisions relating to State or private lands must fit within the constraints of the owner's or manager's purpose and objectives of management. If one of these objectives is maintaining tree growth on forested lands, proper harvesting and utilization is one method to consider. Research results can be useful.

Owner's Objectives

Public Use

Usually means multiple use in some form or other, depending on agency responsible, for example:

Game Department: Wildlife, watershed, recreation, timber production.

State Parks: Usually recreation, possibly watershed, wildlife.

State Forestry: Usually conversion to conifers for timber production.

State Land Department: Often based for single use such as grazing, hunting, mining.

Private

Objectives of owners are changing; recreation, range and wildlife, timber. Often single use on portions. Users often restricted. Could even be complete non-use.

Commercial Use

Most frequently timber production, often as a stage in conversion to conifers. Usually combined with range and wildlife.

Possibly as firebreaks, may include watershed and recreation.

^{1/}Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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Stand Management and Regeneration

Management for What?

Different objectives call for different management. These changes may be due to Agency policy changes or change of ownership. Aspen stands are not alone in this, though it may be emphasized in the Rockies due to esthetic interests.

Harvesting for What?

Sawtimber-Fiber: Yields up to 9,000 board feet/acre at 50 years on good sites have been reported. This would be possible in pure stands only but is probably not very common in the Rockies. Where there is a good market for sawn products or veneer, aspen sawtimber can more than pay its way. While the market is not too good, a fiber market is also needed to develop enough recovery from the harvesting operation.

Roundwood

Including pulpwood, mine timbers, and fuel items, may also be a feasible product where markets can be developed.

Stand Regeneration

Or in some cases stand conversion to other species or improved strains of aspen might be another reason for harvesting aspen stands.

Regeneration Studies

Researchers have found that aspen clones vary greatly in growth rate and stem form,

indicating that, under intensive management, selection of native varieties to favor the outstanding clones could be well worthwhile.

Natural hybrids have been reported from various locations throughout the range of aspen. These hybrids occur between "Quakes" and Bigtooth, and between both of them and white poplar (*P. alba*). Hybrids with European species show considerable promise in both growth rates and quality (Church 1963, Pauley et al. 1963, Einspahr and Benson 1964). There is potential here for developing strains capable of fully utilizing our good sites, producing high quality wood on a short rotation.

Regeneration studies dealing with aspen, seeding, the use of cuttings and seedlings appear to warrant more attention. Perhaps we should be planting aspen as a nurse crop on burns and bug-killed areas in the mixed conifer and spruce zones.

Product Research

Other portions of this symposium are dealing specifically with product research and research needs related to aspen. Let me just mention here that a land manager may want to consider a range of products including:

- Established items (pallets)
- New items (Shakes)
- Primary products (Lumber)
- Secondary products (Molding)
- By-products (Shavings)

Environmental Studies

The role of Rocky Mountain aspen in the overall environment of a given stand or eco-

system tends to be ignored, misunderstood, or misinterpreted, depending on the interests and background of the observer. The cattle rancher likes the open stands for the available forage under them; the sheep herder considers only the browse available to his sheep from this year's sprouts. The Sierra Clubber wants to retain that colorful view. The fire control officer uses aspen stands as firebreaks. The timber manager plans to convert it to conifers.

Perhaps now is the time for all of these different viewpoints and considerations to be brought together in some environmental studies to assist the land manager in deciding what to do with his aspen stands.

In my opinion, the private landowner, usually operating under fewer constraints than the agency land manager, and with his overriding need to make each operation for itself, should be the prime mover in implementation of research results related to aspen management. After all, any tree species that you can harvest for sawlogs at 60-80 years of age offers a quicker economic return than one that must be 120 years old.

References

- Brinkman, Kenneth A., and Roe, Eugene I.
1975. Quaking aspen: Silvics and management in the Lake States. USDA Forest Service Agr. Handbook, 486, 52 p.
- Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen. USDA Forest Serv. Res. Pap. RM-122, 44 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Applying Aspen Research To Industry¹

Lorin D. Porter^{2/}

Abstract.--By applying research to our management decisions, we can penetrate enough markets that the demand for our aspen will increase, causing the price to increase to a point that it can become profitable for us to continue manufacturing aspen.

We, at Western Pine Industries, have been forced to examine the research available concerning aspen because at our Chama, New Mexico operation our supply of timber is made up of about 25 to 40% aspen.

Some aspen research information which has been valuable to us is the research concerning the various uses of the product (Pallet material, furniture core, construction strength and acceptance to builders.) We have sold aspen to each of these markets and plan to continue to sell to these markets in the future. Research which has been especially helpful to us in penetrating the furniture market is the research done in the area of aspen drying. From the aspen drying research we learned how to dry the material so that it will remain straight after being ripped into narrow strips

(approx. 1" x 1-1/2" x 4') which can be used by furniture manufacturers only if they are straight.

Another market in which research has helped us make decisions is our market for aspen paneling. Much of the upper grade paneling is used for paneling which is a beautiful product. This product also needs special drying attention to be sure it remains marketable after drying.

Finally we are exploring a market which through research and development may have great potential for aspen. This is the shingle or roofing market. At this time, it is in the experimental stage and we are not sure what the ultimate market will be, but we are encouraged with the results thus far.

In summary, we feel that by applying research to our management decisions we will be able to penetrate enough markets that the demand for our aspen will increase, causing the price to increase to a point that it can become profitable for us to continue manufacturing aspen.

^{1/} Paper presented at the symposium on Utilization and Marketing as Tools for Aspen Management in the Rocky Mountains, Ft. Collins, Colorado, Sept. 8-9, 1976.

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Symposium Summary

William R. Wilcox^{1/}

It is a difficult job and rather dubious honor to be called on to summarize the lively discussions of this symposium. I'm not sure I know how to do it, particularly since it will be recorded for posterity in the proceedings.

I think it is first necessary to re-examine the stated purpose as set forth in the announcement of the symposium. "The purposes of this symposium are to bring available information on western aspen utilization into focus, and to explore the potential for improved management through increased marketing opportunities."

Did we accomplish these purposes for the entire 4.1 million acres of commercial aspen in the Rocky Mountains? My answer is "No, I don't think so." The key word is focus. While we have succeeded in focusing on some specific utilization opportunities, we can see that they are only a start in terms of what will be needed to solve the aspen manager's problems. The extent of utilization needs will not be fully resolved until management prescriptions are more thoroughly developed. And as Bruce Hronek stated, "We land managers are very confused about aspen."

As brought out in the discussion by John Jones and Don Perala, there is a real problem as to whether managers should thin or not thin aspen stands. Another question raised by Bud Hittenrauch, is whether to clearcut or not. Still another is what should the rotation age be for Rocky Mountain aspen? Most speakers talked in terms of 80 years, but when a member of the audience asked the question, "Why 80 years?", there was no specific answer. The question of increased or decreased forage

production immediately after harvest could not be definitely settled either.

While these are management questions beyond the scope of this symposium, it is obvious that they are fundamental to finding utilization solutions. Therefore, perhaps we should ask, "Have we really focused on production and marketing opportunities?"

One marketing aspect was quickly and simply, yet dramatically, summed up by Keith Runyon: "I'm as confused about what to do with aspen lumber as you are about harvesting it. We sell it to get it the hell out of the yard." He also added that the marketing of aspen should be planned before the tree is cut, not just left to chance. Yet Lonnie Porter of Western Pine Sales reported success in coping with this same problem.

Most of the other utilization speakers spoke along the same general theme of "the tremendous opportunity that aspen presents." We heard of at least 50 opportunities, but one unusual product that sticks in my mind was a search by a Japanese firm for 20 million board feet per year to be used in chopsticks. It doesn't cost any of us much to speak in glowing terms of opportunities. But the moment of truth comes for you in industry when you decide about investing the dollars required to produce and market aspen products. For forest managers, it's a question of deciding how much of your scarce operating collars you're going to put into aspen management. Did our discussions here help you make those decisions?

For the other stated purpose of the symposium--"to explore the potential for improved management through increased marketing opportunities"--I could repeat another equally discouraging list of things we didn't accomplish. But I will limit my comments to Dave Betters' report on the tremendous diversity he found in aspen ecosystems on one national forest--the Routt--demonstrating just how far both researchers and managers still have to go in learning how to manage this species.

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Throughout this symposium, I heard considerable buck-passing between an about equally divided group of land managers and wood utilization people. The utilization people say there are tremendous opportunities if the land managers would just make the timber available. Otherwise a tremendous resource will be allowed to waste away on the stump. Similarly, I heard management people say we want to do something, but there are no markets. One very specific statement I heard, "They (meaning processors) have to take out the aspen component in our sales, but I don't know what they do with it and don't care." Or, finally, the managers and processors both say, "Sure, here are all these tremendous market potentials but not a single one is economical." This kind of buck-passing obviously won't get us anywhere.

First I said, "No, we didn't accomplish the stated purposes of the meeting," and now I've even questioned the purposes. But this doesn't mean the symposium wasn't worthwhile. Far from it.

We did accomplish at least one important thing in the last two days. We have started talking together on the aspen situation as land managers, utilization specialists, and industry. We recognize our shortcomings--"our great pool of ignorance" as Norb DeByle put it--but at least we have made a start. This is a very, very positive accomplishment as far as I'm concerned. There is hope because, as Dave Lowery stated, "Today's Rocky Mountain aspen problems and opportunities are the same set of problems that our Canadian neighbors and the Lake States faced 5 to 10 years ago." They are well on their way to a solution and so are we. We have taken that first step, and I think one man has had a lot to do with getting us started. I would like to close by leading a round of applause for that man--Gene Wengert--whose research provided the impetus for the Symposium and who took the lead in developing the program.

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Gen. Tech. Rep. RM-29, 120 p. Rocky Mt. For. and Range Exp. Stn.,
Fort Collins, Colo. 80521.

Uncontrolled wildfire, which used to assure regeneration of Rocky Mountain aspen, is no longer socially acceptable. Harvesting is therefore necessary to prevent this unique forest type from reverting to coniferous forest. The status of our knowledge about utilization as a tool in aspen management is summarized in 33 papers in five areas: perspectives on Rocky Mountain aspen resource, aspen ecology and harvesting responses, market opportunities and limitations, research advances in aspen utilization, and applying research information to aspen management decisions.

Keywords: Aspen management, aspen symposium.

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**MISTLETOE LITERATURE OF
THE WORLD: A User's Guide to a
FAMULUS Retrieval System**

STLETOE LITERA
THE WORLD: A User's Guide
FAMULUS Retrieval System
Robert F. Scharpf, Frank G. Hawksworth, and Bernard J. Erickson

USDA Forest Service
General Technical Report RM-30
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MISTLETOE LITERATURE OF THE WORLD: A User's Guide to a FAMULUS Retrieval System

Robert F. Scharpf,¹ Frank G. Hawksworth,² and Bernard J. Erickson²

A computer-based information retrieval system to the world literature on the mistletoes presently contains nearly 7,000 citations; about 2,100 of those are on the dwarf mistletoes. Information for each citation is included under these fields: author, date of publication, title, publication source, species of mistletoe, geographic location, major and minor keywords, and an abstract. Searches may be requested from the authors.

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MISTLETOE LITERATURE OF THE WORLD: A User's Guide to a FAMULUS Retrieval System

Introduction

Biological scientists are aware of the increasing volume of technical literature generated each year. Even in specialized fields of interest—forest pathology, for example—retrieval of published literature and keeping abreast of current information are becoming formidable tasks. As a result, scientists are relying to a great extent on computer-based information retrieval systems. Many abstracting and indexing services are now computerized. Several information centers now handle information bases relating to plant pathology (Dwinell 1970). However, a problem in retrieving information in a specialized field is that the scientist may have to search several data bases, which is costly and time consuming. To minimize these problems, specialized systems have been developed to serve the needs of researchers requiring information in a relatively restricted field.

FAMULUS (Burton et al. 1969, USDA FS 1969) is one of these systems. It is a computer-based system designed to handle the personal documentation activities of individual scientists. Examples of its use are for viral diseases of insects (Martignoni et al. 1973), and for a bibliography of lodgepole pine (Lotan and Sweet 1975). We have used FAMULUS to document a comprehensive personal index of information on a specific subject—the mistletoes.

The purposes of this user's guide are:

- To provide a means by which scientists and others can readily obtain information on the mistletoes; and
- To illustrate how FAMULUS can be used as a personal documentation system of information for the scientist.

In brief, FAMULUS consists of eight subsystems by which information can be stored, added, edited, and retrieved. The system also provides 10 fields in which the information for each citation can be included: author(s), date of publication, title of the article, and related information. A more detailed explanation of the fields used for the mistletoe index will be discussed in the section entitled "Information Base."

The Reference Collection

The value of any documentation system depends on the information it contains. The information included in this index is, for the most part, the result of several decades of intensive literature search. A review of the approximately 3,000 citations accumulated up to 1960 was published by Gill and Hawksworth (1961). The collection now contains nearly 7,000 citations, most of which are abstracted or annotated; it covers not only scientific literature on the mistletoes, but also includes items taken from annual reports of various agencies, textbooks, anonymous contributions, and even newspaper articles. Such an index needs to be updated periodically to include new and older, overlooked citations. Approximately 200 journals and abstracting systems are screened periodically. New citations are incorporated once or twice a year. Currently 300 to 400 citations are added annually.

The Information Base

The information is contained in a number of fields, and can be retrieved by various methods from these fields. The fields of mistletoe information and their abbreviations are:

- | | Field |
|----|---|
| 1 | Author (AUTH) |
| 2 | Date (DATE) |
| 3 | Title (TITL) |
| 4 | Publication (PUBL) |
| 5 | Genus and species (SPEC) |
| 6 | Distribution (DIST) |
| 7 | Major keyword (MAJK) |
| 8 | Minor keyword (MINK) |
| 9 | Abstract (ABST) |
| 10 | Dummy (DUMM). (Not used at present, but may be used later.) |

1. Author Field (AUTH)

This field contains the author(s), if known, otherwise a designation of "anonymous" is used. If a paper has more than four authors the first author followed by "et al" is used.

2. Date Field (DATE)

This field contains the date of publication (year). If the date of publication is not known, it is left blank.

3. Title Field (TITL)

The title field includes the complete title of the citation in its original language. If the article is in a language other than English, translation of the title is included in parentheses. For titles that cannot be typed using the Roman alphabet (Japanese, for example), only the English translation is used.

4. Publication Field (PUBL)

The publication field includes the original source of the citation. English abstracts of foreign papers and articles in less accessible journals are included as a secondary source of information.

The guide for title abbreviations (American Chemical Society 1974) as used by **Biological Abstracts** and **Chemical Abstracts** has been used for most recent citations. Many older citations are not now entered under these standard abbreviations, but we plan to convert them to this standard as time permits.

5. Genus and Species Field (SPEC)

In this field, the mistletoes are treated with regard to what we considered their importance. Thus, the most important group, *Arceuthobium* (dwarf mistletoes), is separated by individual species (Hawksworth and Wiens 1972). Two other mistletoes of importance are separated by genus; *Phoradendron*, because it is the other mistletoe occurring in North America, and *Viscum*, because it is the mistletoe most widely studied and best known. All other mistletoes are included under (1) general, a term used to designate articles dealing with several mistletoes, (2) other, or (3) unknown, when the genus and species are not known. Additional subdivision into other genera and species is possible if needed.

The genus and species field as compiled is listed below. If five or fewer species of *Arceuthobium* are mentioned in an article, each is listed. If more than five species are mentioned, the article is listed under *Arceuthobium* spp. "General" includes papers dealing with three or more genera of mistletoes.

The categories presently in the genus and species field are:

<i>Arceuthobium</i> spp.	<i>A. juniperi-proceræ</i>
<i>A. abietinum</i>	<i>A. laricis</i>
<i>A. abietis-religiosae</i>	<i>A. microcarpum</i>
<i>A. americanum</i>	<i>A. minutissimum</i>
<i>A. apacheum</i>	<i>A. occidentale</i>
<i>A. azoricum</i>	<i>A. oxycedri</i>
<i>A. bicarinatum</i>	<i>A. pini</i>
<i>A. blumeri</i>	<i>A. pusillum</i>
<i>A. californicum</i>	<i>A. rubrum</i>
<i>A. campylopodum</i>	<i>A. strictum</i>
<i>A. chinense</i>	<i>A. tsugense</i>
<i>A. cyanocarpum</i>	<i>A. vaginatum</i>
<i>A. divaricatum</i>	<i>A. verticilliflorum</i>
<i>A. douglasii</i>	<i>Phoradendron</i>
<i>A. gillii</i>	<i>Viscum</i>
<i>A. globosum</i>	General
<i>A. guatemalense</i>	Other
<i>A. hondurensense</i>	Unknown

6. Distribution Field (DIST)

This field indicates the geographic location of the mistletoes reported in the citations. Only the location or distribution as reported in the article is listed, even though a particular mistletoe may have a much broader geographic distribution. The most precise geographic breakdown is for North America. The remaining areas have been arbitrarily handled as broad geographic regions.

General
United States, California
United States, Southwest (Ariz, N. Mex., Tex.)
United States, Pacific Northwest (Ore., Wash., Alaska)
United States, Rocky Mountain (Idaho, Nev., Utah, Mont., Wyo., Colo.)
United States, West (West of Rocky Mts., excluding Hawaii)
United States, East (East of Rockies)
Canada, West (B.C., Alberta)
Canada, East (Other provinces)
Mexico
Central America (including West Indies)
South America (including Galapagos)
Africa (including Madagascar)
Australia
New Zealand
Europe (including all of Russia and the Azores)
Asia, Near East (Turkey, Arabian Peninsula, Iran)
Asia, India (including Pakistan, Nepal, Afghanistan, Ceylon)
Asia, China (including Taiwan, Japan, Korea, Tibet)
Asia, Other (Indochina, Indonesia, Philippines, New Guinea)

Other (Pacific Islands, including Hawaii)

Unknown

Maps

7 and 8. Major and Minor Keywords (MAJK and MINK)

The major keywords describe what is considered to be the important information in the citation, while minor keywords narrow the description. The MAJK has been described as the descriptor field. No authoritative vocabulary exists for a reference collection of this sort; thus the keywords used were arbitrarily decided upon by the authors. As the index is updated, new keywords may be added. Users will be provided with new keyword lists periodically. The major (MAJK) keywords and the minor (MINK) keywords under them are:

ANATOMY

- General
- Flowers-fruit
- Root system
- Shoots-leaves
- Ultrastructure

BIBLIOGRAPHIES

BIOCHEMISTRY—see PHYSIOLOGY-

BIOCHEMISTRY

BIOTIC FACTORS (Effects on mistletoe)

- General
- Algae
- Animals (Refers to animals other than birds. Citations dealing with wild animals are keyed here. Uses of mistletoes as food by domestic animals or man are keyed under USES (MAJK) and FOOD-FODDER (MINK)).

- Birds
- Dodder
- Fungi
- Insects (Including mites)

COMPREHENSIVE

CONTROL

- General
- Biological
- Chemical
- Silvicultural
- Silvicultural, fire
- Silvicultural, pruning

CULTURE

CYTOLOGY

DAMAGE (Effects on hosts)

- Agricultural lands
- Bark
- Brooming
- Economic
- Growth

Mortality

Predisposition, insects

Predisposition, fungi

Recreational lands

Seed crops

Swelling

Wood

Yields (Both mortality and growth loss)

ECOLOGY

Fire

Habitat types

EMBRYOLOGY

General

Chromosomes

Other

EPIDEMIOLOGY

General

Germination

Infection

Intensification

Life cycles

Penetration

Seed dispersal

Spread

Viability

EVOLUTION

EXTINCTION (Reports of mistletoes that are very rare, endangered, or extinct)

FLORA

GENERAL BIOLOGY

GENETICS

Hybrids

Sex ratio

GEOGRAPHY

HOSTS

Introduced (Host introduced into the range of a mistletoe)

HOST-PARASITE PHYSIOLOGY

INCIDENCE REPORTS

INTRODUCTION (Establishment of mistletoes outside their natural range)

MORPHOLOGY

General

Flowers-fruits

Root system

Shoots-leaves

NOMENCLATURE

PALEOBOTANY

PALYNOLOGY

PARASITISM

General

Autoparasitism

Dual (Parasitism of an individual tree by two or more mistletoes)

Hyperparasitism

Hypersensitivity

Mimicry (Similarity of mistletoes to host plants)

PHENOLOGY

- General
- Flowering period
- Dispersal period

PHYSICAL FACTORS

- General
- Climate
- Elevation
- Insolation
- Pollution
- Site quality
- Soil
- Topography
- Other

PHYSIOLOGY-BIOCHEMISTRY

- General
- Alkaloids
- Amino acids
- Ash analyses
- Carbohydrates
- Enzymes
- Flavonols
- Hormones
- In vitro culture
- Lipids
- Minerals
- Nitrogen
- Organic acids
- Phenolics
- Photosynthesis
- Protein
- Respiration
- Translocation
- Viscin
- Water relations

POPULAR ARTICLES

PROGRESS REPORTS

PROPOSALS (Research proposals, plans, etc.)

RATING SYSTEMS

RESISTANCE

SURVEYS

- Aerial
- Extensive
- Intensive
- Techniques

TAXONOMY

THESIS

TOXICOLOGY

USES

- General
- Folklore-legend
- Food-fodder
- Pharmaceutical
- Other

9. Abstract

An abstract is provided wherever possible. These abstracts are usually from the original article or from an abstracting journal, but the authors have prepared many of them.

Use of the System

With FAMULUS, information may be searched and retrieved in various ways. Any one or more of the fields can be searched. Searches can be broad or quite specific. Generally, the broader the search, the greater the number of citations that will be included, the higher the search costs, and the more the scientist may have to sort through the citations to get the desired information. On the other hand, very restricted searches may not always yield the information desired.

Before a search is undertaken, the person submitting the request should decide as precisely as possible what information is desired. A search of "everything available on dwarf mistletoes," for example, would yield more than 2,100 citations. The average researcher would not find such a body of information particularly useful.

Specific searches are often best and if more information is needed, additional searches can be made.

Following are some examples of recent search requests:

—Physiology-Biochemistry, all mistletoes: 366 citations.

—Hyperparasitism of mistletoes by other mistletoes: 64 citations.

—*Arceuthobium americanum*: 499 citations.

—Dwarf mistletoes as agents predisposing trees to insect attack: 33 citations.

—Folklore and legend, all mistletoes: 151 citations.

Searching by geographic distribution or genus and species (for *Arceuthobium*) can shorten the citation list and fulfill specific needs. When searching for information on a given genus or species, however, it is necessary to remember that not all citations available will be retrieved by searching for the genus or species name only. Some will also occur in citations listed as "*Arceuthobium* spp.," "Others," or "General."

To obtain adequate information about certain fields of interest, the major and minor keyword fields should be carefully examined. For instance,

if one were interested in pollen and pollination of mistletoes, the keywords to be searched might include: (1) biotic factors—insects; (2) epidemiology—pollination; and (3) palynology. Thus, some requests may require more than one major and minor keyword search.

The keyword field is the simplest method by which citations can be searched for content, because the keywords are intended to describe the principal information in the citations. Additional information may be obtained from a search of specific words in both the title and abstract fields. However, this approach to searching citations is more time consuming and costly. Thus, unless specifically requested, title and abstract searches will not be included in searches.

Requests for searches may be sent to the authors. The authors would appreciate being notified of any errors or omissions in information received from search requests to help improve the collection and keep it up to date.

Literature Cited

American Chemical Society.

1974. Bibliographic guide for editors and authors. 362 p. Am. Chem. Soc., Wash., D. C.
Burton, Hilary D., Robert M. Russell, and Theodor B. Yerke.

1969. FAMULUS: A computer based system for augmenting personal documentation efforts. USDA For. Serv. Res. Note PSW-193, 5 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Dwinell, L. David.

1970. Electronic information retrieval. *Phytopathol. News* 4(9):2-5, 7.

Gill, Lake S., and Frank G. Hawksworth.

1961. The mistletoes—a literature review. U.S. Dep. Agric., Tech. Bull. 1242, 87 p.

Hawksworth, Frank G., and Delbert Wiens.

1972. Biology and classification of the dwarf mistletoes (*Arceuthobium*). U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Lotan, James E., and Donda C. Sweet.

1975. A partially annotated bibliography of lodgepole pine literature 1954-1973. In Management of lodgepole pine ecosystems, Symposium Proc., D. M. Baumgartner (ed.) 2:659-825. Wash. State Univ.

Martignoni, M. E., P. Williams, and D. E. Reinecke.

1973. Computer based catalog of viral diseases of insects: A FAMULUS application. *J. Invert. Pathol.* 22:100-107.

U.S. Department of Agriculture. Forest Service.

1969. FAMULUS: A personal documentation system—A users manual. USDA For. Serv., Pacific Southwest For. and Range Exp. Stn., Misc. Publ. 39 p. Berkeley, Calif.

Acknowledgments

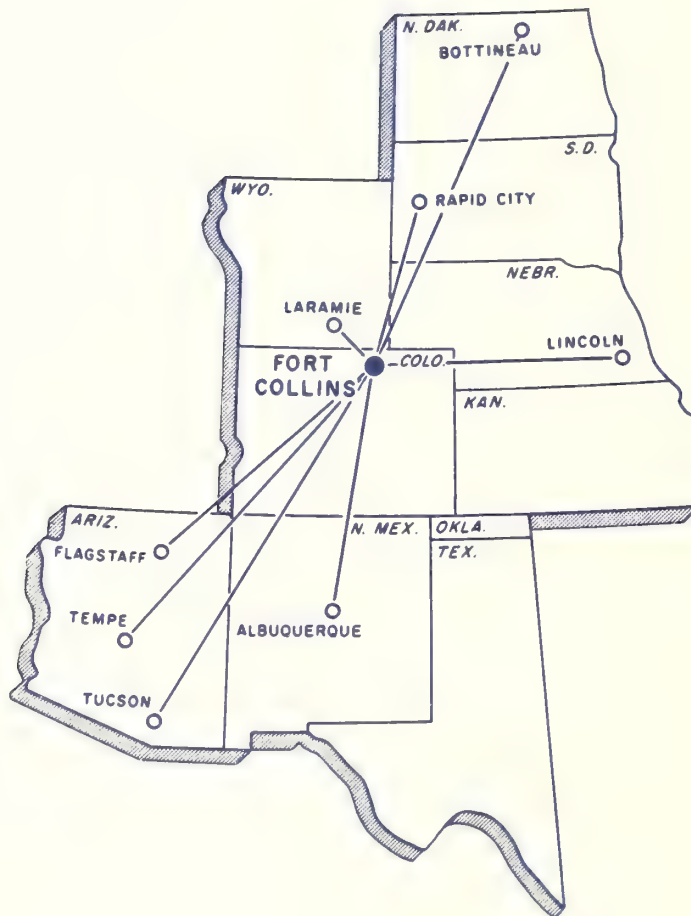
We acknowledge the assistance of Cynthia Jacobs and Jim Clarke, computer specialists at the Pacific Southwest Station, Berkeley for help in design of the Index, editing of cards and tapes, and for providing the necessary computer expertise to successfully complete the Index and get it operational.

Scharpf, Robert F., Frank G. Hawksworth, and Bernard J. Erickson.

1976. Mistletoe literature of the world: A user's guide to a FAMULUS retrieval system. USDA For. Serv. Gen. Tech. Rep. RM-30, 5 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

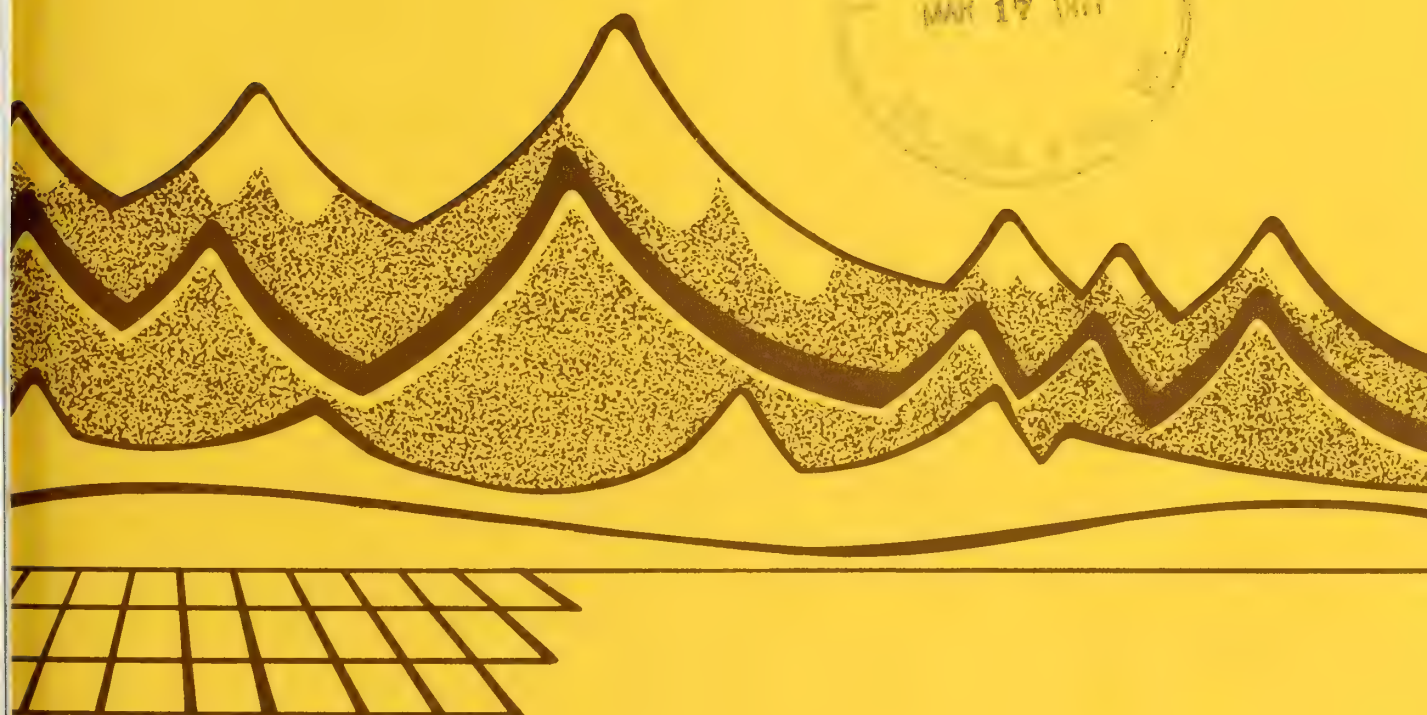
A computer-based information retrieval system to the world literature on the mistletoes presently contains nearly 7,000 citations; about 2,100 of those are on the dwarf mistletoes. Information for each citation is included under these fields: author, date of publication, title, publication source, species of mistletoe, geographic location, major and minor keywords, and an abstract. Searches may be requested from the authors.

Keywords: Loranthaceae, Viscaceae, *Arceuthobium*, *Viscum*, *Phoradendron*.



Rocky Mountain Forest and Range Experiment Station: A list of published research

April 1, 1972 through March 31, 1976



USDA Forest Service
General Technical Report RM-31

November 1976

**Rocky Mountain Forest and
Range Experiment Station**
Forest Service
U. S. Department of Agriculture
Fort Collins, Colorado 80521

Foreword

For years, we prepared an annual report entitled *Forestry Research Highlights*. The last issue covered 1971.

In 1973, we joined with the other Forest Service Experiment Stations in the West — Intermountain, Pacific Northwest, and Pacific Southwest — to print a publication entitled *Forestry Research, What's New in the West*. It is produced two to four times a year and carries feature stories about ongoing research plus short articles on recent publications of import to resource managers. The types of information previously included in our annual report are now covered by this publication which transfers research highlights to resource managers and other interested persons throughout the West. If you are not receiving *Forestry Research, What's New in the West* and would like to, send us a note and we will place you on the mailing list.

We have not printed a consolidated list of Station publications, by subject categories, since our last annual report (though we continue to send our quarterly publications list to thousands of interested persons and institutions). Therefore, we thought it appropriate to assemble this annotated list for the succeeding research years — April 1, 1972 through March 31, 1976. We hope it will help you identify publications of the period that might be useful to you.

In addition, we have just completed the History of Forest Service Research in the Central and Southern Rocky Mountain Regions 1908-1975 (General Technical Report RM-27). It contains a summary of major developments throughout the Station's history including much of the 4 year period since our last annual report. If you would like a copy of the history, or any of the publications listed here that are in print, write to:

Publications Distribution
Rocky Mountain Forest and Range Experiment Station
240 West Prospect
Fort Collins, Colorado 80521



DAVID E. HERRICK

Director

Rocky Mountain Forest and Range Experiment Station
November 1976

**Rocky Mountain Forest and Range Experiment Station:
A List of Published Research,
April 1, 1972 through March 31, 1976**

The Rocky Mountain Forest and Range Experiment Station maintains central headquarters at Fort Collins, in cooperation with Colorado State University.

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Note: This list is an initial effort to assign these research publications to subject categories. No attempt is made to cross reference or provide a comprehensive indexing system. Many publications could be appropriately listed under several subjects. In this list, however, they appear only once in what seems to be the most pertinent category.

FIRE AND ATMOSPHERIC SCIENCES

*Private, State or Federal cooperator

Fuels, Fire Danger

DEEMING, JOHN E., JAMES W. LANCASTER, MICHAEL A. FOSBERG, R. WILLIAM FURMAN, AND MARK J. SCHROEDER.*

1972.

National fire-danger rating system.

USDA For. Serv. Res. Pap. RM-84, 165 p.

The NFDR System produces three indexes -- occurrence, burning, and fire load -- that measure relative fire potentials. These indexes are derived from the fire behavior components -- spread, energy release, and ignition -- plus a consideration of risk. Contains instructions and tables to manually compute the indexes and components for nine broad fuel models.

DEEMING, JOHN E., JAMES W. LANCASTER, MICHAEL A. FOSBERG, R. WILLIAM FURMAN, AND MARK J. SCHROEDER.*

1974.

National Fire-Danger Rating System.

USDA For. Serv. Res. Pap. RM-84, 53 p. (Rev.)

The NFDR System produces three indexes--occurrence, burning, and fire load--that measure relative fire potentials. These indexes are derived from the fire behavior components--spread, energy release, and ignition--plus risk. This revision provides the information necessary to understand and apply the system, but contains computational tables for only one of nine fuel models.

DEEMING, JOHN E.

1975.

Calculating fire-danger ratings: Computer vs. tables. Fire Manage. 36(1):6-7, 9.

Fire-danger rating values derived using NFDRS tables often differ somewhat from computer-derived values. Operational significance of the differences is small, however. The computer is more accurate and consistent, but the manual method is adequate.

DEEMING, JOHN E., AND JAMES K. BROWN.*

1975.

Fuel models in the National Fire-Danger Rating System.

J. For. 73:347-350.

Fuel models were developed to provide data for the Spread and Energy Release Components of the NFDR System. The models quantitatively describe physical and chemical properties of fuel elements and fuel beds that govern flammability. Nine models representing broad vegetative types have been developed.

FOSBERG, MICHAEL A.

1972.

Theory of precipitation effects on dead cylindrical fuels.

For. Sci. 18:98-108.

Numerical and analytical solutions of the Fickian diffusion equation were used to determine the effects of precipitation on dead cylindrical forest fuels. The analytical solution provided a physical framework. The numerical solutions were then used to refine the analytical solution through a similarity argument. The theoretical solutions predicted realistic rates of water exchange and the internal distribution of the water. The theory also (1) predicted that precipitation duration rather than amount or rate determined the amount of water uptake and (2) provided a function useful in practical applications.

FOSBERG, MICHAEL A.

1973.

Empirical refinement of the theoretical moisture diffusivity.

Wood Sci. 6:190.

Responds to comments by Bramhall and Warren (4(4):245-247) on a previous article by Fosberg et al.: Laboratory and theoretical comparison of desorption in ponderosa pine dowels, 3(2):94-99. Bramhall's reply follows.

FOSBERG, MICHAEL A.

1973.

Prediction of prepyrolysis temperature rise in dead forest fuels.

Fire Technol. 9:182-188.

The heat transfer rate to forest fuels ahead of a flaming fire front is highly variable over the interval of time required to preheat the fuels. An analytical function was derived which permitted inclusion of this varying transfer rate in the calculation of temperature rise for forest fuels.

FOSBERG, M. A.

1975.

Prediction of water vapor flux in conifer forest litter and duff.

Bull. Am. Meteorol. Soc. 56:112. (Abstr.)

This theoretical model of heat and vapor transport in forest soils includes particle sorption processes as well as porous media flow. It is primarily for predicting forest floor moisture for wildfire danger and fire behavior and effects.

FOSBERG, MICHAEL A.

1975.

Heat and water vapor flux in conifer forest litter and duff: A theoretical model.

USDA For. Serv. Res. Pap. RM-152, 23 p.

The model was developed from numerical and analytical solutions of the diffusion forms of the mass continuity equation and the first law of thermodynamics. Analytical solutions provided a functional framework to evaluate nonlinear interactions obtained in the numerical solutions.

FOSBERG, MICHAEL A.

1975.

Prediction of water vapor flux in conifer litter and duff.

Conf. Agric. For. Meteorol. [Tucson, Ariz., Apr. 1975] Proc. 12:21-22. Am. Meteorol. Soc., Boston, Mass.

The model more closely describes the physical processes in sorbing porous media than models based on hydraulic conductivity or diffusivity. Also, it is very responsive to vapor exchange processes. Qualitative predictions by the model compare well with observations.

FURMAN, R. WM.

1972.

A stochastic model for deriving the moisture content of heavy fuels.

Am. Meteorol. Soc. Bull. 53:1032. (Abstr.)

The model estimates moisture content of 3/4- to 3-inch fuels in terms of persistence and observed 1/2-inch stick moisture. The model depends on a Monte Carlo simulation of a segmented exponential distribution. Correlation between predicted and measured fuel moisture is 0.94.

FURMAN, R. WILLIAM, AND ROBERT S. HELFMAN.*
1973.

Computer time-sharing used with NFDRS.
Fire Manage. 34(2):14-16.

A computer communications system is described that can collect meteorological information, compute fire-danger ratings, and display this information upon request.

FURMAN, R. WILLIAM.
1975.

Estimating moisture content of heavy forest fuels.
For. Sci. 21(2):135-139.

A linear model estimates moisture content of the 100-hour timelag fuels. Variables include yesterday's computed value for 100-hour timelag fuel moisture, today's observed 10-hour timelag fuel moisture, and a binary variable which is set if it has rained in the past 24 hours.

HELFMAN, ROBERT S.* JOHN E. DEEMING, ROBERT J. STRAUB, AND R. WILLIAM FURMAN.

1975.

User's guide to AFFIRMS: Time-share computerized processing for fire danger rating.

USDA For. Serv. Gen. Tech. Rep. RM-15, n.p. [107 p.]

Procedures for processing fire-danger data utilizing a time-share computer via a remote terminal are presented in language for persons without computer background. Input includes fuels and weather information; output includes messages sent from other users, displays of observed and forecasted weather, and fire danger indexes.

MCCAMMON, BRUCE P., AND DAVID A. RAINEY.

1973.

Fire-danger index generation.

Hewlett-Packard Keyboard 5(1):17-18.

A modification of a FORTRAN IV program, which calculates real time fire danger indices, was developed to be used as a research tool and to provide a quick, accurate method of calculating values from the field.

MC CAMMON, BRUCE P.

1974.

Snowpack influences on dead fuel moisture.

Bull. Am. Meteorol. Soc. 55:71. (Abstr.)

Fuels approached fiber saturation during the snowpack accumulation period. The short melt period provided very little liquid water for further moisture uptake. Large, dead, forest fuels emerge from a snowpack at approximately 32 percent moisture content by weight.

STRAUB, ROBERT J.

1975.

Cost reduction for AFFIRMS display options.

Fire Manage. 36(1):8-9.

Changing the display format is the least painful way to reduce the cost of AFFIRMS. Some ways to cut costs: Use short displays, carefully suppress headings, minimize use of SIG and Forest displays, consolidate displays to minimize display commands.

Hazard Reduction, Controlled Use of Fire

DEEMING, JOHN E., AND DALE D. WADE.*

1974.

A clarification...wildfire suppression terminology.

Fire Manage. 35(3):10-11.

Suppression firing is the general term describing the intentional application of fire to speed up or strengthen wildfire control action. It includes the tactical terms counter firing, burning out, and mopup burning. Firing techniques used include head fire, flank fire, backfire, etc.

Effects of Fire, Fire Ecology

CABLE, DWIGHT R.

1972.

Fire effects in southwestern semidesert grass-shrub communities.

Tall Timbers Fire Ecol. Conf. [Lubbock, Tex., June 1972] Proc. 12:109-127.

Planned burning can limit the encroachment of shrubby species into grassland, and prevent them from reaching seed-bearing size. It will seldom increase perennial grass production, may reduce production temporarily, and will probably change relative abundance of perennial grass species.

KRUSE, WILLIAM H.

1972.

Effects of wildfire on elk and deer use of a ponderosa pine forest.

USDA For. Serv. Res. Note RM-226, 4 p.

After a wildfire, elk use shifted from an old seeded clearcut to a newly seeded burn for the first 2 years. The third year showed an equalizing trend of elk use between the two habitat conditions. The trend of decreasing deer use on thinned areas continued, but use increased substantially on the wildfire area.

PEARSON, H. A., J. R. DAVIS, AND G. H. SCHUBERT.

1972.

Effects of wildfire on timber and forage production in Arizona.

J. Range Manage. 25:250-253.

A severe May wildfire decimated an unthinned ponderosa pine stand; an adjacent thinned stand was relatively undamaged. Radial growth increased on burned trees with less than 60 percent crown kill. Burning initially stimulated growth and nutrient value of herbaceous vegetation in both stands. Seeded areas produced most herbage after 2 years.

SCHOLL, DAVID G.

1975.

Soil wettability and fire in Arizona chaparral.

Soil Sci. Soc. Am. Proc. 39:356-361.

Relatively cool fires caused water repellence at the surface. Hot fires caused repellence at greater depth, but the surface layer was rendered completely wettable. Organic matter decreased at progressively higher temperatures. Organic material causing repellence is almost completely lost above 270 C.

Fire Management, Fire Behavior

DEEMING, JOHN E., AND R. WILLIAM FURMAN.

1974.

Automation of the National Fire Danger Rating System--impacts on fire management.

Bull. Am. Meteorol. Soc. 55:68. (Abstr.)

Experience with the interactive time-share computer system was very encouraging. Time required to process observations and forecasts was comparable to that needed to complete hand calculations. Overall, costs were considered reasonable.

LINDENMUTH, A. W., JR., AND JAMES R. DAVIS.

1973.

Predicting fire spread in Arizona's oak chaparral.

USDA For. Serv. Res. Pap. RM-101, 11 p.

Existing fire models did not adequately predict rate-of-spread (ROS). A statistical model developed using essentially the same input variables but weighted differently accounted for 81 percent of the variation in ROS. A coefficient that accounts for effects of fuel chemistry is applied to the model.

LANCASTER, JAMES W.

1972.

Fire danger rating for loggers' use.

West. For. Fire Comm. [Seattle, Wash., Dec. 1972] **Annu. Meet. 1972:15-19.** **West. For. Conserv. Assoc., Portland, Oreg.**

The National Fire Danger Rating System predicts fire occurrence, behavior, and containment by means of related components and indexes. It is now used primarily for presuppression planning, but should have wide application in regulating forest use.

LANCASTER, JAMES W.

1973.

Practical applications of the National Fire-Danger Rating System.

Eighth Annu. Meet. Middle Atlantic Interstate For. Fire Protection Compact. [Cape Henlopen State Park, Lewes, Delaware, Sept. 18-20] **Proc., p. 43-51.**

Describes the fire behavior components and fire management indexes of the NFDR System, and how managers can use them in presuppression planning.

LANCASTER, JAMES W.

1974.

Fire management applications of the National Fire Danger Rating System.

Bull. Am. Meteorol. Soc. 55:70. (Abstr.)

Increased capabilities of the National Fire Danger Rating System have given fire managers new tools for evaluating various facets of fire management problems. Examples of suggested approaches for use of NFDR numbers in prevention, presuppression planning, and in initial attack efforts are presented.

LANCASTER, JAMES W.

1974.

Fire management applications of the National Fire Danger Rating system.

SAF-AMS Joint Conf. on Fire and For. Meteorol. [Lake Tahoe, Calif., Apr. 1974] **Pap., 27 p.**

Increased capabilities of the NFDR System have given fire managers new tools for evaluating various facets of fire management problems. Suggested approaches for use of NFDRS numbers in prevention, presuppression planning, and in initial attack efforts are presented. Specific examples are shown.

Weather, Meteorology, Climatology

BERGEN, JAMES D.

1972.

Windspeed distribution in and near an isolated clearing in a pine stand.

Am. Meteorol. Soc. Bull. 53:1028. (Abstr.)

Ratios of measured speeds to estimated friction velocity calculated from speeds on a reference tower above the canopy were almost constant over a wide range of speeds and stabilities. The clearing is filled with level or ascending flow, with subsidence in the lee.

BERGEN, JAMES D.

1974.

Variation of windspeed with canopy cover within a lodgepole pine stand.

USDA For. Serv. Res. Note RM-252, 4 p.

The linear correlation computed for 22 points in a lodgepole pine canopy suggests independence between the point-to-point variations in speed at any level and variations of total canopy cover.

BERGEN, JAMES D.

1974.

Variations of air temperature and canopy closure in a lodgepole pine stand.

USDA For. Serv. Res. Note RM-253, 3 p.

Air temperatures were scaled by temperature gradient over the canopy, and point-to-point variation of this scaled temperature from deviations of canopy view factor. Results indicate independence at all the levels for which temperature was measured.

BERGEN, JAMES D.

1974.

The independence of the point-to-point variations in windspeed and temperature in a lodgepole pine stand.

USDA For. Serv. Res. Note RM-258, 2 p.

The correlation between local variations in air temperature and windspeed at particular levels in a pine stand are examined for evidence of persistent momentum transport by thermal convection. The results argue against such an effect.

BERGEN, JAMES D.

1974.

Airflow velocities and separation patterns in a forest clearing as indicated by smoke drift measurements.

Bull. Am. Meteorol. Soc. 55:74. (Abstr.)

Cinematic observations were made of the behavior of multiple smoke plumes in an isolated clearing cut in an even-aged stand of lodgepole pine. The results indicate a continuous alternation between separated and unseparated flow. The effect appears relevant to the behavior of forest roads in regard to pollutant emission and fire spread.

BERGEN, JAMES D.

1974.

Vertical air temperature profiles in a pine stand: Spatial variation and scaling problems.

For. Sci. 20:64-73.

Results indicate strong horizontal temperature variation in the crown space in an even-aged lodgepole pine stand. Horizontal movement of sensible heat could be comparable to that in the vertical. A composite temperature profile indicates maximum temperatures at the level of maximum foliage and at the stand floor.

BERGEN, JAMES D.

1974.

The relation between density, grain size and solar albedo for natural snow cover.

EOS Trans. Am. Geophys. Union 56:1117. (Abstr.)

A simple model is proposed for the solar albedo of natural snow cover. The model is based on the Carmen-Kozney relation between sieve grain size, snow density, and air permeability developed by Bender.

BERGEN, J. D.

1975.

The windflow in an isolated forest clearing.

Bull. Am. Meteorol. Soc. 56:116. (Abstr.)

Widening a narrow clearing in a lodgepole pine forest from one tree height in width to three increased scaled windspeeds at almost all points by factors approaching 200 percent.

BERGEN, JAMES D.

1975.

An approximate analysis of the momentum balance for the airflow in a pine stand.

p. 287-298. In Heat and mass transfer in the biosphere. Part 1. Transfer processes in the plant environment, edited by D.A. deVries and N.H. Afgan. 594 p. Scripta Book Co., Wash., D.C.

An approximate model of airflow in a pine canopy is used to estimate velocity profiles, volume drag coefficient, and effective viscosity from windspeed and foliage distribution measurements. Live branches are the characteristic drag element, and viscosity has an appreciable dispersive component.

BERGEN, J. D.
1975.

Air movement in a forest clearing as indicated by smoke drift.

Agric. Meteorol. 15:165-179.

Cinematic observations indicate a continuous alternation between separated and unseparated flow. The flow sequence includes a central vortex, which appears to dominate the distribution and direction of the maximum speed and surface shear stress in the clearing.

BERGEN, JAMES D.
1975.

A possible relation of albedo to the density and grain size of natural snow cover.

Water Resour. Res. 11(5):745-746.

A simple model is proposed for the solar albedo of natural snow cover, based on an approximation to the specific surface by a function of grain size and density derived from air permeability measurements. Agreement with limited observational material is good. The model suggests that, for grain sizes greater than 1.5 mm, density is the primary factor governing albedo.

CAMPBELL, RALPH E.
1972.

Prediction of air temperature at a remote site from official weather station records.

USDA For. Serv. Res. Note RM-223, 4 p.

Air temperatures at the San Luis experimental watershed were predicted from temperatures at Albuquerque, New Mexico on the basis of linear regressions between temperatures at the two locations calculated from a full year of continuous record at San Luis and official 3-hour records at Albuquerque. Predictions of daily mean temperatures at San Luis were within plus or minus 3.8 degrees F. Monthly mean temperatures for a given time of day were predicted within plus or minus 3.6 degrees to 5.5 degrees depending on time of day. Hourly temperatures were predicted within plus or minus 6.3 degrees to 7.8 degrees depending on time of day. All of these were within the 80 percent tolerance interval. Within + or - 3.8 degrees F. Monthly mean temperatures for a given time of day were predicted within + or - 3.6 degrees to 5.5 degrees depending on time of day. Hourly temperatures were predicted within + or - 6.3 degrees to 7.8 degrees depending on time of day. All of these were within the 80 percent tolerance interval.

DEEMING, JOHN E., AND WILLIAM G. SULLIVAN.*
1974.

Automation of the National Fire Danger Rating System--impacts on the fire weather forecaster.

Bull. Am. Meteorol. Soc. 55:68. (Abstr.)

National Weather Forecast Offices in Arizona and California participated in the field trials of AFFIRMS (Automatic Forest Fire Information Management and Retrieval System). Communication of fire weather observations from the field to the forecaster and of fire weather forecasts from the forecaster to the users was greatly simplified.

FOSBERG, MICHAEL A., ALBERT RANGO,* AND WILLIAM E. MARLATT.*
1972.

Wind computations from the temperature field in an urban area.

Conf. Urban Environ. 2d Conf. Biometeorol. (Phila., Pa., Oct.-Nov. 1972) Proc., p. 5-7. Am. Meteorol. Soc., Boston, Mass.

A simple computation is proposed through which the wind field may be estimated from the observed temperature field. Integration of the circulation theorems by use of mean value theorems gives an expression for the vorticity. The stream function may then be determined from the vorticity through the choice of appropriate boundary conditions.

FOSBERG, MICHAEL A., AND R. WILLIAM FURMAN.
1973.

Fire climates in the Southwest.

Agric. Meteorol. 12:27-34.

Temperature and humidity were used to define mean equilibrium moisture content during season of high fire danger. Phenological stages of lesser herbaceous vegetation were taken as integrators of available moisture, and were used to evaluate moisture content of the fine fuel complex, which influences fire behavior.

FOSBERG, MICHAEL A., AND WILLIAM E. MARLATT.*
1974.

Calculation of airflow over complex terrain: I. Theory and model characteristics.

Bull. Am. Meteorol. Soc. 55:74. (Abstr.)

A mesoscale numerical model of boundary layer flow has been developed for use in complex terrain. The local flow characteristics are calculated from the thermodynamic structure by mean-value integration of the body forces. These local flow characteristics are superimposed on a background flow to obtain the total wind field.

FOSBERG, MICHAEL A., W. E. MARLATT,* AND LAWRENCE KRUPNAK.*
1975.

Estimation of airflow over complex terrain.

Bull. Am. Meteorol. Soc. 56:190. (Abstr.)

A one-layer model of boundary-layer flow was developed through use of impulse accelerations of thermal and frictional forces to modify the terrain-induced potential flow field. This model uses only data routinely collected in mountainous terrain.

FOSBERG, MICHAEL A., WILLIAM E. MARLATT,* AND LAWRENCE KRUPNAK.*
1976.

Estimating airflow patterns over complex terrain.

USDA For. Serv. Res. Pap. RM-162, 16 p.

A diagnostic model of the vector flow field requires much less data than traditional approaches, and therefore can be used as an estimator of wind patterns in areas where dense observational networks are not feasible. Intended primary uses are in providing wind fields for predicting fire. Intended primary uses are in providing wind fields for predicting fire behavior and evaluating pollution transport patterns.

FOSBERG, MICHAEL A.

1976.

New technology for determining atmospheric influences on smoke concentrations.

p. 148-159. In Air quality and smoke from urban and forest fires. Int. Symp. [Fort Collins, Colo., Oct. 1973] Proc. Natl. Acad. Sci., Wash., D.C. 381 p.

A numerical diagnostic model of atmospheric boundary layer flow, developed for use in mountainous wildland areas, is based on a mean value integration of the body forces in the vorticity and divergence forms of the Navier-Stokes equations. The model is readily adaptable to many environmental problems; data may be from direct observation or remote sensing of the thermal structure of the atmosphere.

FURMAN, R. WILLIAM, AND ROBERT S. HELFMAN.*
1973.

A computer program for processing historic fire weather data for the National Fire-Danger Rating System.

USDA For. Serv. Res. Note RM-234, 12 p.

FIRDAT is a FORTRAN IV program to compute the daily components and indexes of the National Fire-Danger Rating System. FIRDAT will also compute and print the absolute, relative, and cumulative frequencies of occurrence, and print a cumulative frequency distribution for each of the components and indexes.

FURMAN, R. WILLIAM.
1975.

An aid to streamlining fire-weather station networks.

USDA For. Serv. Gen. Tech. Rep. RM-17, 4 p.

A method is proposed for determining degree of duplication in monitoring fire climate, based on an analysis of similarity of sequences of six fire climate elements over the fire season.

FURMAN, R. WILLIAM, AND GLEN E. BRINK.

1975.

The national fire weather data library: What it is and how to use it.

USDA For. Serv. Gen. Tech. Rep. RM-19, 8 p.

The National Fire Weather Data Library is a computerized collection of daily weather conditions from fire weather stations across the Nation. Current data are accumulated on collection tapes, then merged onto library tapes annually. Example outputs are given for the UNIVAC 1108 computer at USDA's Fort Collins Computer Center.

GARY, HOWARD L.

1975.

Canopy weight distribution affects windspeed and temperature in a lodgepole pine forest.

For. Sci. 20:369-371.

Weight distribution of needles plus branches approximated a normally distributed population for 10 randomly selected trees in an 80-year-old stand in southern Wyoming. Windspeeds were minimum and midday air temperatures maximum in the midcanopy region where needles and branch weight were concentrated.

MARLATT, WILLIAM E.,* AND MICHAEL A. FOSBERG.

1974.

Calculation of airflow over complex terrain: II. Application of the WINDS model to problems of environmental impacts in mountainous regions.

Bull. Am. Meteorol. Soc. 55:74. (Abstr.)

The numerical model described in the previous paper has been used operationally to solve a number of practical problems associated with possible environmental impacts in mountainous regions. Applications of the WINDS model in studies of power plant siting, strip mining, prescribed burning, and ski development will be demonstrated.

MARLATT, W. E.,* AND M. J. (A.) FOSBERG.

1976.

WINDS--A model for calculating the boundary layer flow and air pollution potential in complex terrain.

Bull. Am. Meteorol. Soc. 57(2):279. (Abstr.)

The model is based on terrain, thermally and frictionally induced flows superimposed on a background potential flow, and incorporates both divergence and vorticity. It has been used successfully for studies of air pollution potential and design of air quality maintenance areas.

THILENIUS, JOHN, AND DENNIS KNIGHT.*

1975.

Snow duration and growing season microclimate in alpine tundra and subalpine meadows.

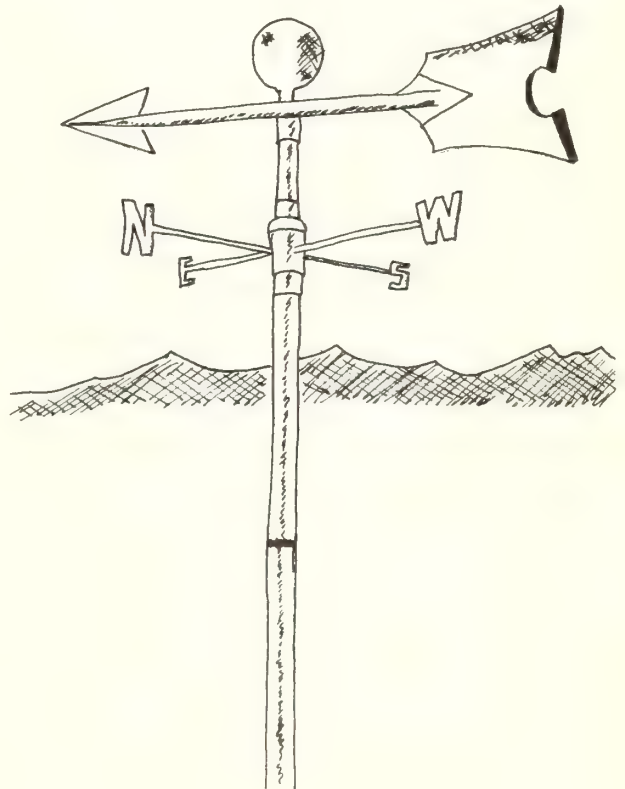
p. 23-37. In *The Medicine Bow ecology project, final report, February 28, 1975*. D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.

Summarizes the microclimatic regimes of two alpine tundra and four subalpine meadow sites over a 2-year period, including air and soil temperatures, solar radiation, rainfall and snow accumulation, soil moisture, windspeed, vapor pressure deficit, and relative humidity. (Entire report available from NTIS, 397 p., \$3.)

p. 259-273. In *Man, leisure, and wildlands: A complex interaction*. [Proc. First Eisenhower Consortium Res. Symp., Sept. 14-19, 1975, Vail, Colo.] Eisenhower Consortium Bull. 1, 286 p.

Air quality considerations and modeling techniques to evaluate environmental impacts of mountain and wildland developments are presented. A suggested procedure provides for quantification of air pollutants emitted from concentrated recreation facilities, and identification of their effects. Suggested regional air quality maintenance plans should incorporate continual monitoring.

Blowing Snow: See Snow Fences, Blowing Snow under WATERSHED MANAGEMENT



Air Pollution

FOX, DOUGLAS G.

1975.

Impact of concentrated recreational development on air quality.

FOREST INSECTS AND DISEASES (Including Controls)

*Private, State or Federal cooperator

Seedling Diseases

PETERSON, GLENN W.
1974.

Disease problems in the production of containerized forest tree seedlings in North America.
p. 170-172. In North Am. Containerized For. Tree Seedling Symp. [Denver, Colo., Aug. 1974] Proc. Great Plains Agric. Counc. Publ. 68, 458 p.

Severe losses of Douglas-fir and other conifers by grey mold and damping-off can be expected in greenhouses if humidity remains high in vicinity of seedlings. Losses can be reduced by increased movement of air near seedlings, by fungicides, and by sanitation.

PETERSON, GLENN W., AND RICHARD S. SMITH, JR.
{TECH. COORD.}
1975.

Forest nursery diseases in the United States.
U.S. Dep. Agric., Agric. Handb. 470, 125 p.

Discusses hosts, symptoms, damage, life cycles, distribution of pathogens, and methods for control for 31 diseases of seedlings in forest nurseries--9, root; 8, stem and branch; 14, foliage. Includes a short discussion on storage molds, plus selected references, glossary, disease index, and host index.

Foliage and Twig Diseases

PETERSON, GLENN W.
1972.

Chemical control of Phomopsis blight of junipers: A search for new methods.
Tree Plant. Notes 23(3):3-4.

Only phenyl mercury fungicides effectively control phomopsis blight, but environmental constraints severely restrict their use. Other fungicides proved ineffective against phomopsis in the literature are listed to prevent duplication of research.

PETERSON, GLENN W.
1973.

Biology and control of some conifer diseases encountered in landscapes in the midwestern United States.

Woody Ornamental Dis. Workshop [Columbia, Mo., Jan., 1973] Proc. 1:111-128.

Discusses Dothistroma needle blight, brown spot needle blight, Lophodermium needlecast, and Diplodia tip blight of pines, and Phomopsis blight and Cercospora blight of junipers.

PETERSON, GLENN W.
1973.

Infection of *Juniperus virginiana* and *J. scopulorum* by *Phomopsis juniperovora*.
Phytopathology 63:246-251.

Nonwounded new foliage was highly susceptible to infection; lesions did not develop on old foliage. Germination of spores, germ-tube development, and growth in culture were optimum near 24 C. Disease development was enhanced by high post-incubation temperatures (32 C.).

PETERSON, GLENN W.
1973.

Infection of Austrian and ponderosa pines by *Dothistroma pini* in eastern Nebraska.

Phytopathology 63:1060-1063.

Conidia were trapped by May 15. They were disseminated only during periods with rain. Current-year needles were not infected before July 13, older needles as early as May 20. Symptoms appear 11-16 weeks after infection. June-September rainfall is a good indicator of amount of infection to be expected.

PETERSON, GLENN W., AND DAVID A. GRAHAM.*
1974.

Dothistroma needle blight of pines.

U.S. Dep. Agric. For. Pest Leaflet. 143, 5 p.

This fungus can be severely damaging, especially in Christmas tree plantations. Twenty North American pines and hybrids are known hosts. Copper fungicides effectively prevent infection, but timing depends on variable susceptibility of current and previous-years' needles.

PETERSON, GLENN W.
1974.

Infection of shoots and cones of Austrian pine by *Diplodia pinea*.

Proc. Am. Phytopathol. Soc. [Vancouver, B.C., Aug. 1974] 1:110. (Abstr.)

D. pinea severely damages Austrian, ponderosa, and Scots pines over 30 years old in Great Plains plantings. Two applications of Bordeaux mixture between April 24 and May 8 reduced shoot infection 87 percent. Applications after May 14 were ineffective. These applications to protect shoots did not protect susceptible second-year cones, however.

PETERSON, GLENN W.
1975.

Dothistroma needle blight: A problem in production of landscape pines.

Am. Nurseryman 141(12):11, 94-96.

The most likely source of this fungus is on infected seedlings, such as lining stock, brought into the nursery. Bordeaux mixture applied in early May will protect old needles; a mid-June application is necessary to protect new needles. Only one application, in mid-June, will give satisfactory protection in most years.

PETERSON, GLENN W., AND C. S. HODGES, JR.*
1975.

Phomopsis blight of junipers.

U.S. Dep. Agric., For. Pest Leaflet. 154, 6 p.

Phomopsis juniperovora blight is common in nurseries from the Great Plains to the Atlantic, primarily on eastern redcedar and Rocky Mountain juniper. Young, unwounded needles are susceptible throughout the growing season. Since mercury fungicides can no longer be used, Benomyl is the only fungicide registered for controlling phomopsis.

STALEY, J. M., AND H. H. BYNUM.*
1972.

A new *Lophodermella* on *Pinus ponderosa* and *P. attenuata*.

Mycologia 64:722-726.

Lophodermella morbida, an aggressive pathogen of pine foliage, was collected from northern California, Oregon, and Washington locations west of the Cascade crest. Evidence suggests the fungus is endemic and limited to environments having moist, moderate climates.

STALEY, J. M.
1975.

The taxonomy of *Lophodermia* on pines, with special reference to problems in North American Christmas tree plantations.

p. 79-85. In *Lophodermium* in pines. Proc. 5th Eur. Colloq. For. Pathol. [Schmalenbeck, Apr. 1975.]

A species concept for *Lophodermium pinastri* based on the type specimen cited by Chevallier is described as essential to resolution of taxonomic complexities among *Lophodermia*. Symptomological, phenological, morphological, and cultural characteristics can be used to separate the various taxa.

STALEY, J. M.

1973.

The development on, and penetration into *Pinus sylvestris* foliage, of a pathogenic *Lophodermium*.

p. 43-45. In *Lophodermium* in pines. Proc. 5th Eur. Colloq. For. Pathol. [Schmalenbeck, Apr. 1975.]

A *Lophodermium* species distinct from *L. pinastri* is capable of attacking current year and older foliage of *Pinus sylvestris*. Ascospores appear to lodge at irregularities on wet needle surfaces. Penetration hyphae enter directly through the cuticle and epidermis. The pathogen is readily controlled by maneb, benlate, or fundalin.

UECKER, F. A.,* AND J. M. STALEY.

1973.

Development of the ascocarp and cytology of *Lophodermella morbida*.

Mycologia 65:1015-1027.

Events of a 1-year life cycle are described. Cytology, and development of asci from an ascogenous hyphal system with crozier formation, are typical of many ascomycetes. The haploid number of chromosomes is 8 or 9.

WHEELER, MARGARET M.,* DESMOND M. S. WHEELER,* AND GLENN W. PETERSON.

1975.

Anthraquinone pigments from the phytopathogen *Phomopsis juniperovora* Hahn.

Phytochemistry 14:288-289.

The yellow-orange coloration that forms on agar in diagnostic tests for *P. juniperovora* is primarily due to 7-methoxy-2-methyl-1,2,3,4,5-pentahydroxy-1,2,3,4-tetrahydroanthraquinone.

Root and Stem Diseases

HINDS, T. E.

1972.

Ceratocystis canker of aspen.

Phytopathology 62:213-220.

Several species of *Ceratocystis* are associated with a trunk canker on quaking aspen. *C. fimbriata* is a causal agent. The primary point of canker initiation is at fresh bark wounds.

HINDS, T. E.

1972.

Insect transmission of *Ceratocystis* species associated with aspen cankers.

Phytopathology 62:221-225. (Reprinted in: J.W. Brewer and M.D. Harrison, eds. 1973. Readings in insect-plant disease relationships. p. 267-278. MSS Inf. Corp., N.Y.)

Nitidulids are considered the principal vectors of *Ceratocystis* canker of aspen in Colorado. Two rove beetles and a root-eating beetle were also vectors of *C. fimbriata* and other *Ceratocystis* species.

HINDS, T. E., AND R. W. DAVIDSON.*

1972.

Ceratocystis species associated with the aspen ambrosia beetle.

Mycologia 64:405-409.

A new species, *Ceratocystis retusi*, characterized by brown perithecia and long flexuous, ostiolar filaments, is described.

This species and *C. brevicollis* were commonly found in the pupal cells of the aspen ambrosia beetle, *Typodendron retusum*, in Colorado.

HINDS, T. E., AND R. W. DAVIDSON.*

1975.

Two new species of *Ceratocystis*.

Mycologia 67(4):715-721.

Describes *Ceratocystis ponderosae*, from blue stain of ponderosa pine, and *C. fraxinopennsylvanica*, from brown stain in bark beetle galleries of green ash. *C. ponderosae* is morphologically similar to *C. pilifera* but differs in growth habit and staining ability. The ostiolar tip and imperfect state of *C. fraxinopennsylvanica* are characteristic.

HINDS, T. E., AND R. G. KREBILL.*

1975.

Wounds and canker diseases on western aspen.

U.S. Dep. Agric., For. Pest Leaflet. 152, 9 p.

Trunk wounds to the fragile, living bark are the most common entrance points for canker disease fungi, the most serious cause of aspen mortality. No chemical control measures are known.

HINDS, T. E.

1976.

Aspen mortality in Rocky Mountain campgrounds.

USDA For. Serv. Res. Pap. RM-164, 20 p.

Aspens die from canker infections as a result of bark injuries inflicted by thoughtless campers. Dead trees usually are cut to reduce hazard. Aspen loss is related to campground age. A desirable unit can be degraded to a treeless site within 10 to 20 years.

LIGHTLE, PAUL C., AND JOHN H. THOMPSON.*

1973.

Atropellis canker of pines.

U.S. Dep. Agr. For. Pest Leaflet. 138, 6 p.

Four *Atropellis* fungi collectively cause widespread canker disease of hard and soft pines throughout much of the U.S. and Canada. Control is based on silvicultural techniques to remove the source of inoculum, infected trees.

PETERSON, GLENN W.

1973.

Dispersal of aeciospores of *Peridermium harknessii* in central Nebraska.

Phytopathology 63:170-172.

Dispersal of western gall rust spores increased sharply in the morning as air temperature increased and relative humidity decreased. This periodicity was interrupted by rain. Aeciospore dissemination began in early May and was essentially complete by the end of June.

WYSONG, DAVID S.,* AND JERRY W. RIFFLE.

1975.

Cytospora canker of poplars and willows.

NebGuide G75-257, B-2, 4 p. Nebr. Univ., Lincoln.

Cytospora chrysosperma is one of several fungal pathogens that cause stem cankers on hardwood trees. The symptoms, disease cycle, and control of *Cytospora* canker on poplars and willows in Nebraska are described in this extension leaflet.

Mistletoes and Other Higher Parasitic Plants

ALEXANDER, MARTIN E., AND FRANK G. HAWKSWORTH.

1975.

Wildland fires and dwarf mistletoes: A literature review of ecology and prescribed burning.

USDA For. Serv. Gen. Tech. Rep. RM-14, 12 p.

Wildfires may either inhibit or encourage these parasites, depending primarily on the size and intensity of the burn. Fire

exclusion policies of the past half century may have increased dwarf mistletoe levels and fire potential. Prescribed burning may be a supplemental control tool in some forest types and stand conditions.

GREGOR, SUSAN,* DELBERT WIENS,* ROBERT E. STEVENS, AND FRANK G. HAWKSWORTH.

1974.

Pollination studies of *Arceuthobium americanum* in Utah and Colorado.

Southwest. Natur. 19:65-73.

A. americanum, a dwarf mistletoe parasitic on *Pinus contorta*, is thought to be insect pollinated since at least 25 insect species were observed on pistillate and staminate flowers. Diptera and Hymenoptera were most common.

HAWKSWORTH, FRANK G., AND DELBERT WIENS.*
1972.

Biology and classification of the dwarf mistletoes (*Arceuthobium*).

U. S. Dep. Agric., Agric. Handb. 401, 234 p.

Describes 32 recognized taxa: 28 species, 5 subspecies, and 2 *formae speciales*. Classification system is based on extensive field studies of New World species, examination of specimens in major herbaria of North America and Europe, and computer analyses of all taxonomic data.

HAWKSWORTH, F. G.

1972.

Biological control of the mistletoes.

p. 83-92. In Biological control of forest diseases. Int. Union For. Res. Organ. XV Congr. [Gainesville, Fla., Mar. 1971] Subj. Group 2, 105 p. Ottawa, Can. For. Serv.

Several insects and fungi are specific to dwarf mistletoes, but exert only a low degree of natural control. Most promising are certain canker fungi that inhabit host bark near mistletoes and limit mistletoe shoot production.

HAWKSWORTH, FRANK G.

1972.

Dwarf mistletoe control.

West. For. Pest Comm. [Seattle, Wash., Dec. 1972] Annu. Meet. 1972:51-52. West. For. Conserv. Assoc., Portland, Oreg.

Control efforts, as yet exclusively silvicultural, have been minimal because managers didn't know if the effort was economically justifiable. Yield simulation programs that include effects of mistletoe provide needed economic information. Some programs are now available for even-aged stands; programs for uneven-aged stands are being developed.

HAWKSWORTH, F. G.

1973.

Dwarf mistletoes (*Arceuthobium*) of coniferous forests of the world.

Eur. Weed Res. Counc. Symp. Parasit. Weeds [Malta, April 1973] Proc. 1973:231-235.

Briefly discusses the biology, means of dispersal, ecology, and methods of cultural and biological control of the dwarf mistletoes.

HAWKSWORTH, F. G.

1973.

On a new power source.

J. Irreproducible Results 20(1):20.

Describes the vast potential energy produced by exploding dwarf mistletoe fruits in coniferous forests throughout the West. Advocates harvesting this new power source to help alleviate the nation's energy crisis.

HAWKSWORTH, FRANK G., AND ED F. WICKER.*

1973.

***Nectria flammae* associated with scale insects on dwarf mistletoe in Honduras.**

Turrialba 23:365-367.

Describes the imperfect stage of the fungus on two scale insects, *Hemiberlesia rapax* and *Aspidiotus nerii*, which are parasitic on the rare dwarf mistletoe, *Arceuthobium hondurense*.

HAWKSWORTH, FRANK G.

1974.

Mistletoes on introduced trees of the world.

U.S. Dep. Agric., Agric. Handb. 469, 49 p.

This worldwide inventory includes only introduced host situations, where a tree is grown outside its natural range and within that of a particular mistletoe. First the mistletoes are listed alphabetically with the introduced hosts reported for each; the second section is a host index. (Available from Superintendent of Documents, Stock No. GPO 0100-03303, 75 cents.)

HAWKSWORTH, FRANK G.

1975.

Dwarf mistletoe and its role in lodgepole pine ecosystems.

p. 342-358. In Manage. Lodgepole Pine Ecosyst. Symp. [Pullman, Wash., Oct. 1973] Proc., 2 vols. David M. Baumgartner, ed. Wash. State Univ., Pullman.

Discusses hosts, distribution, biology, epidemiology, effects, and control of lodgepole pine dwarf mistletoe. Interactions with other elements of the ecosystem are emphasized, including role in forest succession, fire ecology, habitat types, and faunal associates. Yield tables for mistletoe-infested stands are also described.

HAWKSWORTH, FRANK G.

1975.

Free diseases.

p. 406-407. In Yearbook of Science and Technology, 1974. 460 p. McGraw-Hill, N.Y.

Dwarf mistletoes are generally small parasitic plants that live on conifers. Pines are most commonly affected. Growth reduction and mortality are often severe. Control requires pruning infected branches, or removing infected trees or stands.

HAWKSWORTH, FRANK G., JAMES T. FISHER,* AND ROBERT L. MATHIASSEN.*

1975.

An unusual occurrence of *Arceuthobium cyanocarpum* on ponderosa pine near Boulder, Colorado. Plant Dis. Rep. 59(9):758-759.

This dwarf mistletoe usually parasitizes limber pine. It was found more than 2,000 feet lower and 5 miles away from the closest known populations of this taxon on limber pine. The common ponderosa pine dwarf mistletoe also occurs in the stand, and some trees are parasitized by both dwarf mistletoes.

HAWKSWORTH, FRANK G., AND MELVYN J. WEISS.*

1975.

***Arceuthobium gillii* in New Mexico.**

Southwest. Nat. 20(3):418.

Extends the known range of Chihuahua pine dwarf mistletoe from Arizona and Mexico into extreme southwestern New Mexico in the Animas mountains.

LIGHTLE, PAUL C., AND FRANK G. HAWKSWORTH.

1973.

Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona.

USDA For Serv. Res. Pap. RM-106, 22 p.

Describes the control effort, and compares treated and untreated stands after 20 years. The original goal -- to reduce the level of dwarf mistletoe and protect the ponderosa pine forest -- has been achieved. Recommendations for dwarf mistletoe control in recreational forests are summarized.

LIGHTLE, PAUL C., AND ESLIE H. LAMPI.*

1973.

Herbicides ineffective in controlling southwestern dwarf mistletoe.

USDA For. Serv. Res. Note RM-242, 3 p.

The oil-soluble amine and butoxyethanol ester of

2,4,5-trichlorophenoxy butyric acid (4-(2,4,5,-TB)) in concentrations of 0.5, 1.5, and 3.0 percent were ineffective in reducing infection levels of the parasite in ponderosa pine trees in northern New Mexico.

LIGHTLE, PAUL C., AND MELVYN J. WEISS.*
1974.

Dwarf mistletoe of ponderosa pine in the Southwest.
U.S. Dep. Agric., For. Pest Leaflet. 19, 8 p. (Rev.)

Southwestern dwarf mistletoe spreads slowly through stands of ponderosa pine. Growth is retarded, and trees die slowly. Explosive discharge of fruits is responsible for nearly all spread. Characteristic witches' brooms indicate infection. Only silvicultural control methods are available.

MARK, WALTER R.,* AND FRANK G. HAWKSWORTH.
1974.

How important are bole infections in spread of ponderosa pine dwarf mistletoe.
J. For. 72:146-147.

Infections on boles over 5 inches in diameter seem to pose little threat to surrounding trees. Thus larger trees with only bole infections, or bole infections plus prunable light branch infections, need not be removed in control operations.

MC CARTNEY, WILLIAM O.,* ROBERT F. SCHARPF,*
AND FRANK G. HAWKSWORTH.

1973.
Additional hosts of *Viscum album*, European mistletoe, in California.

Plant Dis. Rep. 57:904.

Records the occurrence of this mistletoe on 12 more hosts, 3 of which are native California trees, plus 2 hosts determined by inoculation.

SCHARPF, ROBERT F.,* AND FRANK G. HAWKSWORTH.

1974.
Mistletoes on hardwoods in the United States.
U.S. Dep. Agric. For. Pest Leaflet. 147, 7 p.

Trees heavily infected with mistletoe are weakened, reduced in growth, and sometimes killed. Weakened trees are predisposed to attack by insects, disease, and drought. Control in forests is difficult. On individual trees, infected limbs can be pruned off, or mistletoe shoots can be broken off periodically.

Mycorrhizal Relationships

RIFFLE, J. W.
1972.

Histopathology of *Pinus ponderosa* ectomycorrhizae infected with a *Meloidogyne* species.
Phytopathology 62:785. (Abstr.)

The undescribed nematode was found infecting ectomycorrhizae of mature ponderosa pine in southwestern New Mexico in 1963.

RIFFLE, JERRY W.
1973.

Histopathology of *Pinus ponderosa* ectomycorrhizae infected with a *Meloidogyne* species.
Phytopathology 63:1034-1040.

Nematode larvae penetrated the ectomycorrhizae, migrated to the stelar region, and developed into adults with their heads embedded in vascular tissue. Giant cells developed near the head, distorting and crushing xylem tracheids in the vicinity.

RIFFLE, JERRY W.
1973.

Pure culture synthesis of ectomycorrhizae on *Pinus ponderosa* with species of *Amanita*, *Suillus*, and *Lactarius*.
For. Sci. 19:242-250.

Mycorrhizae were formed during a 5-month period with *Suillus granulatus*, *Amanita muscaria*, *A. pantherina*, and *Lactarius deliciosus*. Morphological-anatomical characteristics of these mycorrhizae are described. The number of confirmed *P. ponderosa* mycorrhizal symbionts is increased from six to ten.

RIFFLE, JERRY W.
1975.

Two *Aphelenchoides* species suppress formation of *Suillus granulatus* ectomycorrhizae with *Pinus ponderosa* seedlings.

Plant Dis. Rep. 59(12):951-955.

Feeding activities of nematodes stopped or slowed fungal growth and prevented mycelia from coming in contact with many of the roots. Nematodes did not suppress fungus viability, however. Nematodes fed only on fungal mycelia; none were found in roots or mycorrhizal cortical tissue.

Plant Nematodes

RIFFLE, JERRY W.
1972.

Effect of certain nematodes on the growth of *Pinus edulis* and *Juniperus monosperma* seedlings.
J. Nematol. 4:91-94.

Hoplotaimus galeatus, *Helicotylenchus pumilis*, *Tylenchus exiguus*, and *Xiphinema americanum* parasitized *P. edulis* seedlings but did not significantly reduce seedling growth. *Xiphinema americanum* and *H. pumilis* parasitized *J. monosperma* seedlings and reduced root weights, root collar diameters, and stem weights. *H. galeatus* and *H. pumilis* entered the seedling roots of both tree species and fed as endoparasites.

RIFFLE, JERRY W.
1973.

Effect of two mycophagous nematodes on *Armillaria mellea* root rot of *Pinus ponderosa* seedlings.
Plant Dis. Rep. 57:355-357.

Aphelenchoides cibolensis and *A. composticola* in flask cultures suppressed development of *Armillaria mellea* root rot of *Pinus ponderosa*. Nematodes greatly reduced mortality due to root rot, and generally reduced seedling weight losses, but neither species killed the fungus.

Non-pathogenic Diseases

SPOTTS, ROBERT A.,* JACK ALTMAN,* AND JOHN M. STALEY.
1972.

Soil salinity related to ponderosa pine tipburn.
Phytopathology 62:705-708.

Symptoms identical to those occurring naturally in Denver were induced with a variety of chloride salt solutions. Induced needle injury and foliar concentration of chloride were highly correlated. Total soluble salt and chloride levels were higher in soils around injured pines than around healthy pines.

Insect Detection, Evaluation, Identification

STEIN, JOHN D., AND PATRICK C. KENNEDY.
1972.

Key to shelterbelt insects in the northern Great Plains.
USDA For. Serv. Res. Pap. RM-85, 153 p.

An insect key designed to help identify 227 insect species. The text contains 136 figures and 8 color plates to aid in identification. Several tables assist in coordinating host damage with a particular insect species.

STEIN, JOHN D.
1974.

Introduction to shelterbelt insects.
Proc. Entomol. Soc. Am., North Cent. Branch 28:197-198. (Abstr.)

Caragana blister beetle, woolly elm aphid, boxelder twig borer, poplar petiolegall aphid, and fall cankerworm were rated most damaging in North Dakota. Western pine tip moth threatens pine plantings in the central Plains, and an elm leaf beetle is serious in central and southern Plains.

STEIN, JOHN D.
1974.

Sampling defoliators in single row shelterbelts.
Proc. Entomol. Soc. Am., North Cent. Branch 28:199. (Abstr.)

Two half-meter twigs from the upper half of the tree was the most effective method of predicting defoliation levels. An average of 36 twigs per belt were required to make a correct prediction.

STEIN, JOHN D., AND DENNIS J. DORAN.
1975.

A nondestructive method of whole-tree sampling for spring cankerworm.
USDA For. Serv. Res. Note RM-290, 4 p.

The use of a backpack mistblower and a pyrethrum compound facilitates whole tree sampling without destroying the trees. This method can be used as a collecting tool or as a means of determining density and distribution of insect populations.

STEIN, JOHN D.
1976.

Insects: A guide to their collection, identification, preservation, and shipment.
USDA For. Serv. Res. Note RM-311, 12 p.

Homeowners can send insects to their State extension entomologist for identification. The basic requirements for proper collection, preservation, and shipment of insects are summarized briefly here. A reference table lists 184 typical or prevalent insects associated with 52 tree and shrub hosts found in North and South Dakota.

Bark Beetles

BUFFAM, P. E.,* C. K. LISTER,* R. E. STEVENS, AND R. H. FRYE.*
1973.

Fall cacodylic acid treatments to produce lethal traps for spruce beetles.
Environ. Entomol. 2:259-262.

Cacodylic acid, applied to basal frills on *Picea engelmannii*, resulted in trap trees lethal to *Dendroctonus rufipennis*. Green trees were treated and felled in September and October; beetles attacking the following summer produced significantly fewer progeny than untreated checks.

LUCHT, D. D.,* R. H. FRYE,* AND J. M. SCHMID.
1974.

Emergence and attack behavior of *Dendroctonus adjunctus* Blandford near Cloudcroft, New Mexico.
Ann. Entomol. Soc. Am. 67:610-612.

Most beetles emerge about 1 year after the parent adults attack. Peak numbers were recorded in the last week of October. A second emergence peak occurs about 2 years after the original attacks. Around 90 percent of the brood completes development in 1 year while the remaining 10 percent mature in 2 years.

MATA, S. A., JR.
1972.

Accuracy of determining mountain pine beetle attacks in ponderosa pine utilizing pitch tubes, frass, and entrance holes.

USDA For. Serv. Res. Note RM-222, 2 p.

Counts of external indicators of attacks by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, throughout the infested length of five sampled ponderosa pines, were 1.5 percent greater than actual attacks.

MC CAMBRIDGE, WILLIAM F., AND FRED B. KNIGHT.
1972.

Factors affecting spruce beetles during a small outbreak.

Ecology 53:830-839.

After a 2-year epidemic, reduced beetle fecundity, due to nematodes and unknown agents, was the first indicator of outbreak decline. Significant summer mortality agents were pitch, competition for food, predation by woodpeckers and flies, and parasitism by wasps. Woodpecker activity caused desiccation of both food and beetle larvae.

MC CAMBRIDGE, WILLIAM F., AND GALEN C. TROSTLE.*
1972.

The mountain pine beetle.

U. S. Dep. Agric. For. Pest Leaflet 2, 6 p. (Rev.)

MC CAMBRIDGE, W. F.
1972.

Treatment height for mountain pine beetles in Front Range ponderosa pine.

USDA For. Serv. Res. Note RM-218, 2 p.

Pitch tubes and intermittent blue stain are generally found about 5 feet above the highest point where significant mountain pine beetle brood is produced; thus, chemical control can be achieved by spraying to 5 feet below the highest pitch tubes.

MC CAMBRIDGE, WILLIAM F.
1974.

Identifying ponderosa pine infested with mountain pine beetles.

USDA For. Serv. Res. Note RM-273, 2 p.

Trees successfully and unsuccessfully attacked by mountain pine beetles have several symptoms in common, so that proper diagnosis is not always easy. Guidelines presented here enable the observer to correctly distinguish nearly all attacked trees.

MC CAMBRIDGE, W. F.
1974.

Influence of low temperatures on attack, oviposition, and larval development of mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Scolytidae).
Can. Entomol. 106:979-984.

Mountain pine beetles attacked logs, mated, and constructed egg galleries slowly at 4.4 C. No eggs were deposited in 6 weeks. Attack and oviposition increased above this temperature. Larvae grew at 4.4 C. Growth at 2.2 C is difficult to prove because of very high mortality among smallest individuals.

MC CAMBRIDGE, WILLIAM F., JOHN LAUT,* AND RON GOSNELL.*
1975.

Fumigate firewood infested with mountain pine beetle.
USDA For. Serv. Res. Note RM-289, 2 p.

Beetles in ponderosa pine firewood can be killed by spraying each cord with 2 gallons of ethylene dibromide emulsion, then covering and sealing the piles with plastic.

MC KNIGHT, M. E., AND D. G. AARHUS.*
1973.

Bark beetles, *Leperisinus californicus* and *L. criddlei* (Coleoptera: Scolytidae), attacking green ash in North Dakota.

Ann. Entomol. Soc. Am. 66:955-957.

Lesperisinus californicus Swaine breeds only in living tissue, usually pruning branches, but it sometimes invades tree boles, causing tree mortality. *L. criddlei* Swaine attacks cut trees, broken branches, trees girdled by rodents, and limbs or stems girdled earlier by *L. californicus*.

MITCHELL, J. C., AND J. M. SCHMID.

1973.

Spruce beetle: Mortality from solar heat in cull logs of Engelmann spruce.

J. Econ. Entomol. 66:401-403.

Solar treatment of naturally infested spruce cull logs in clearcuts gave 90 percent or greater mortality of *Dendroctonus rufipennis* on the top surface of turned logs, but did not significantly increase mortality on their sides. Solar treatment was most effective if logs were turned before July.

SARTWELL, CHARLES,* AND ROBERT E. STEVENS.

1975.

Mountain pine beetle in ponderosa pine: Prospects for silvicultural control in second-growth stands.

J. For. 73:136-140.

Severe tree killing occurs predominantly in dense stands where competition has substantially slowed growth of even the dominant trees. Early results of experiments begun in the 1960's indicate that thinning dense stands deserves major emphasis in efforts to minimize this pest problem.

SCHMID, J. M.

1972.

A problem in the Front Range: Pine beetles.

Colo. Outdoors 21(6):37-39.

Characteristics of infested trees and the life cycle of the beetle are briefly stated. Natural control factors and current control methods are discussed. Long term stability and future status of beetle populations is proposed.

SCHMID, J. M.

1972.

Reduced ethylene dibromide concentrations or fuel oil alone kills spruce beetles.

J. Econ. Entomol. 65:1520-1521.

No living beetles were found in bolts treated with ethylene dibromide at 0.25 pound per 5 gallons of fuel oil (1/6 of current recommendations). Fuel oil alone killed 90 percent of the brood in larval or pupal stages.

SCHMID, J. M., AND ROY C. BECKWITH.*

1972.

The spruce beetle.

U. S. Dep. Agric. For. Pest Leaflet. 127, 7 p.

The spruce beetle annually kills 300-500 million board feet of spruce. Overmature trees are usually attacked first, but all diameter classes may be killed. Most outbreaks originate in blowdowns, but cull logs may also be a contributing factor.

SCHMID, J. M.

1972.

Emergence, attack densities, and seasonal trends of mountain pine beetle (*Dendroctonus ponderosae*) in the Black Hills.

USDA For. Serv. Res. Note RM-211, 7 p.

Beetles began emerging around July 1 and emerged in peak numbers on August 15, 1966 and 1967. Adults emerged almost simultaneously from north and south sides of trees. Relationships between beetle emergence, evaluation techniques, and control operations are discussed.

SCHMID, J. M., AND ROY C. BECKWITH.*

1975.

The spruce beetle.

U.S. Dep. Agric. For. Pest Leaflet. 127, 7 p. (Slightly rev.)

The spruce beetle annually kills 300-500 million board feet of spruce. Overmature trees are usually attacked first, but all

diameter classes may be killed. Most outbreaks originate in blowdowns, but cull logs may also be a contributing factor. (Slightly revised from 1972 issue.)

SCHMID, J. M., AND R. H. FRYE.*

1976.

Stand ratings for spruce beetles.

USDA For. Serv. Res. Note RM-309, 4 p.

Engelmann spruce-subalpine fir stands can be rated for potential spruce beetle (*Dendroctonus rufipennis* (Kirby)) outbreaks on the basis of physiographic location, tree diameter, basal area, and percentage of spruce in the canopy.

STEVENS, ROBERT E.

1972.

Use of silviculture in control of bark beetles (Scolytidae).

VII Nac. Congr. Mex. Entomol. [Mex. City, Oct. 1970]

Folia, Nums. 23-24, p. 87-88.

Carefully controlled logging offers a good way to change the conditions under which insect outbreaks develop. This approach is longlasting, safe, and ecologically harmonious.

STEVENS, ROBERT E.

1973.

Association of *Pityophthorus opimus* with *Pissodes terminalis* in Colorado lodgepole pine (Coleoptera: Scolytidae and Curculionidae).

Coleopt. Bull. 27:141-142.

These observations constitute new host and locality records for *P. opimus*, and also indicate an example of commensalism between the two beetle species.

STEVENS, ROBERT E., AND HAROLD W. FLAKE, JR.

1974.

A roundheaded pine beetle outbreak in New Mexico: Associated stand conditions and impact.

USDA For. Serv. Res. Note RM-259, 4 p.

Dendroctonus adjunctus Blandford infests *Pinus ponderosa* Laws. in mixed second-growth stands in the Sacramento Mountains of south-central New Mexico. In six areas, losses ranged from near 0 to over 50 percent of the ponderosa pine stand component, both in number of trees and basal area.

STEVENS, ROBERT E., CLIFFORD A. MYERS, WILLIAM F. MC CAMBRIDGE, GEORGE L. DOWNING,* AND JOHN G. LAUT.*

1974.

Mountain pine beetle in Front Range ponderosa pine: What it's doing and how to control it.

USDA For. Serv. Gen. Tech. Rep. RM-7, 3 p.

Mountain pine beetle is currently in outbreak status in Rocky Mountain ponderosa pine stands. The cause is partly related to extensive areas of susceptible forest. Combined control programs using all suitable methods are proposed.

STEVENS, ROBERT E., DONN B. CAHILL,* C. KENDALL LISTER,* AND GARY E. METCALF.*

1974.

Timing cacodylic acid treatments for control of mountain pine beetles in infested ponderosa pines.

USDA For. Serv. Res. Note RM-262, 4 p.

Careful timing is critical to success. Infested trees must be treated before any larval galleries exceed 0.5 inch in length. Since the beetle attack period may last more than 1 month, more than one visit per area will be necessary to locate and properly treat all trees that become infested.

Defoliators

STEIN, JOHN D.
1974.

Elm sawfly.

U.S. Dep. Agric., For. Pest Leaflet. 142, 6 p.

Elm sawfly larvae sporadically cause serious defoliation of elms and willows, particularly in urban areas. The large adults gash the bark of small limbs and branches with powerful mandibles to feed on sap.

STEIN, JOHN D.
1974.

Spring cankerworm (*Paleacrita vernata*) (Lepidoptera: Geometridae) feeding on flax as a secondary host.
Can. Entomol. 103:783-784.

After the larvae completely defoliated a Siberian elm shelterbelt in North Dakota, they migrated into a flax field, continued to develop, and pupated in the soil.

STEIN, JOHN D.
1974.

Unusual oviposition sites of *Paleacrita vernata*.

J. Kans. Entomol. Soc. 47:483-485.

Unusual oviposition sites for the spring cankerworm are noted.

STEIN, JOHN D.
1974.

Pupal distribution of the spring cankerworm.

Proc. Entomol. Soc. Am., North Cent. Branch 29:181-182.

Paleacrita vernata spends about 85 percent of its life cycle in the soil. In Siberian elm shelterbelts, 80 percent of the pupae were within 2 m of tree root collars, and 90 percent were at a depth of less than 11 cm.

STEVENS, ROBERT E.
1973.

A ponderosa pine needle miner in the Colorado Front Range.

USDA For. Serv. Res. Note RM-228, 3 p.

A population of *Coleotechnites* needle miners (Lepidoptera: Gelechiidae) caused noticeable defoliation to ponderosa pines in the Boulder area in 1971 and 1972. Life history and habits are similar to those reported for *C. pinella* Busck. Serious tree injury is not expected.

STEVENS, ROBERT E.
1974.

Ponderosa pine needle miners in Colorado.

Proc. Entomol. Soc. Am., North Cent. Branch 28:198. (Abstr.)

Coleotechnites needle miners have been occasionally reported from Colorado since soon after the turn of the century. A current infestation occurs in a narrow band (200-300 ft) at about 6,800 ft in the Front Range of the Colorado Rockies near Boulder.

Borers, Sucking Insects, and Others

BENTON, TERESA A., AND DANIEL T. JENNINGS.
1975.

Pupal anomaly of *Rhyacionia neomexicana* (Olethreutidae).

J. Lepid. Soc. 29(3):192-194.

A female southwestern pine tip moth pupa with an abnormally segmented abdomen was found in the San Juan National Forest in southwestern Colorado. Reports of such anomalies on lepidopterous pupae are rare.

BREWER, J. W.,* AND ROBERT E. STEVENS.
1972.

Biology of the pinyon pitch nodule moth in Colorado.
J. Colo.-Wyo. Acad. Sci. 7:68-69. (Abstr.)

Petrova albicapitana arizonensis emerges and begins oviposition on new pinyon foliage in mid-July. Larvae mine portions of shoots, which curl like a shepherd's crook, then break off. A pitch nodule at point of entrance provides lasting evidence of infestation.

BREWER, J. WAYNE,* AND ROBERT E. STEVENS.
1973.

The pinyon pitch nodule moth in Colorado.

Ann. Entomol. Soc. Am. 66:789-792.

Petrova arizonensis kills shoots and disrupts normal growth of pinyon. Although tops are stunted, lateral growth continues, and the tree maintains a generous complement of foliage overall. The moth has a 1-year life cycle, overwintering as larvae inside pitch nodules.

FLAKE, HAROLD W., JR.,* AND DANIEL T. JENNINGS.
1974.

A cultural control method for pinyon needle scale.

USDA For. Serv. Res. Note RM-270, 4 p.

Washing eggs off host trees is a simple, inexpensive, effective cultural control method. Dislodged eggs, litter, and debris are raked, bagged, and destroyed. Control must be timed to coincide with the egg stage before crawler emergence.

JENNINGS, DANIEL T.
1974.

Potential fecundity of *Rhyacionia neomexicana* (Dyar) (Olethreutidae) related to pupal size.

J. Lepid. Soc. 28:131-136.

Overwintering female southwestern pine tip moth pupae have a mean ovariole complement of 293 oocytes. Oocyte complements for overwintering pupae can be estimated from pupal size measurements.

JENNINGS, DANIEL T.
1974.

Sexing southwestern pine tip moth pupae, *Rhyacionia neomexicana* (Lepidoptera: Olethreutidae).

Ann. Entomol. Soc. Am. 67:142-143.

Pupae of *Rhyacionia neomexicana* (Dyar) can be sexed by location of the genital opening, ventral abdominal coloration pattern, and relative antennal length.

JENNINGS, DANIEL T.
1975.

Distribution of *Rhyacionia neomexicana* eggs within ponderosa pine trees.

Ann. Entomol. Soc. Am. 68(6):1008-1010.

Eggs of the southwestern pine tip moth are deposited on the inner surfaces of needles in upper crowns of small pines. Most eggs are found about 1.5 cm above the needle-fascicle base, on the three uppermost whorls of foliage. Ovipositing females seem to prefer 1-yr-old needles.

JENNINGS, DANIEL T.
1975.

Life history and habits of the southwestern pine tip moth, *Rhyacionia neomexicana* (Dyar) (Lepidoptera: Olethreutidae).

Ann. Entomol. Soc. Am. 68:597-606.

This moth overwinters in cocoons attached to root collars of ponderosa pine. Emerging females mate once in April. Eggs are usually laid in the upper three whorls of foliage. Eggs hatch in June, and larvae pass through five instars and three feeding stages: needle mining, pitch tent and shoot mining.

MC CAMBRIDGE, WILLIAM F.
1974.

Pinyon needle scale.

U.S. Dep. Agric. For. Pest Leaflet. 148, 4 p.

Damage from this sap-sucking insect can be especially serious on esthetically valuable pinyons. Natural controls are generally ineffective, but valuable trees can be protected by spraying with a dimethoate-water emulsion.

MC KNIGHT, M. E., AND A. D. TAGESTAD.
1972.

Megachile centuncularis nest in carpenterworm gallery.

J. Kans. Entomol. Soc. 45:51-53.

A nest of a leafcutter bee was found in a larval gallery of the carpenterworm, *Prionoxystus robiniae* (Peck), in green ash. Damage by this or other species of *Megachile* is common on trees in shelterbelts.

MC KNIGHT, M. E., AND D. G. AARHUS.*
1973.

Notes on weevils from trees and shrubs in North Dakota.

USDA For. Serv. Res. Note RM-230, 4 p.

The red elm bark weevil, the poplar-and-willow borer, an ash seed weevil, the strawberry root weevil, the sweetclover weevil, the lesser alfalfa weevil, and an acorn weevil are widespread and abundant on their respective tree hosts.

MC KNIGHT, M. E., AND SCOTT TUNNOCK.*
1973.

The borer problem in green ash in North Dakota shelterbelts.

N. D. Farm Res. Bimon. Bull. 30(5):8-14.

The probability of damage by the ash borer and the carpenterworm is high, but should not prevent planting where green ash is needed. Effective control involves surveillance, detection, and suppression. Suppression may include insecticides and/or cutting infested trees.

SEXSON, GARY D.,* AND ROBERT E. ROSELLE.*
1974.

Effectiveness of systemic insecticides against the pine tip moth on ponderosa pine.

USDA For. Serv. Res. Note RM-277, 5 p.

Carbofuran 10 percent granules and phorate 15 percent granules (10 pounds active ingredient per acre) were superior for protection of nursery stock against *Rhyacionia bushnellii*. Carbofuran wettable powder (0.25 percent) or dimethoate emulsifiable concentrate (0.125 percent) sprays performed well in nurseries and plantings. Timing of dimethoate applications is critical.

STEVENS, ROBERT E., AND JERRY A. E. KNOFF.*
1974.

Lodgepole terminal weevil in interior lodgepole forests. Environ. Entomol. 3:998-1002.

Pissodes terminalis is a widespread associate of *Pinus contorta* in the central Rocky Mountain and Intermountain areas. Life history and habits are similar to those reported for the species elsewhere. Infestations are heaviest in stands 5-20 ft tall, and decline as trees grow out of this height class.

TUNNOCK, SCOTT,* AND ARDEN TAGESTAD.
1973.

Incidence of wood borer activity in green ash windbreak plantings in North Dakota.

U.S. Dep. Agric., For. Serv., Reg. One, Div. State Priv. For. Rep. 73-5, 13 p. Missoula, Mont.

The carpenterworm can be considered a minor problem in the eastern half of North Dakota. However, the presence of the ash borer in more than half the windbreaks sampled Statewide makes this insect a potential threat to their management. Control measures are available and should be applied where owners are concerned. (Request for copy may be sent to Forest Pest Control Branch, State and Private Forestry, U.S. Forest Service, Federal Building, Missoula, Montana, 59801.)

HOFF, C. CLAYTON,* AND DANIEL T. JENNINGS.
1974.

Pseudoscorpions phoretic on a spider.

Entomol. News 85:21-22.

Two female *Lustrochernes grossus* (Banks) (Chernetidae) were found on the abdomen of a male giant crab spider, *Olios fasciculatus* in Arizona. This is the first report of pseudoscorpions phoretic on a spider.

JENNINGS, DANIEL T.
1972.

An overwintering aggregation of spiders (Araneae) on cottonwood in New Mexico.

Entomol. News 83:61-67.

An overwintering aggregation of 21 spiders was found beneath the starting bark of a Fremont cottonwood limb in Bernalillo County.

JENNINGS, DANIEL T.
1973.

Egg retreat of *Metaphidippus arizonensis* (Peckham) (Araneae: Salticidae) in a hollow stem.

Entomol. News 84:317-320.

Describes the collection of a jumping spider egg retreat spun within the confines of a dry, hollow composite stem.

JENNINGS, DANIEL T.
1974.

Crab spiders (Araneae: Thomisidae) preying on scarab beetles (Coleoptera: Scarabaeidae).

Coleopt. Bull. 28:41-43.

Xysticus apachecus Gertsch crab spiders were collected feeding on adult *Diploptaxis* sp., *D. parvicollis* Fall, and *Phyllophaga (Listrochelus) falsa* (LeConte) scarab beetles on young *Pinus ponderosa* Laws. trees in Arizona. New records of prey, spider-habitat associations, and predators of scarab beetles are established by these collections.

JENNINGS, DANIEL T., AND HERBERT ALLEN PASE, III.*

1975.

Spiders preying on *Ips* bark beetles.

Southwest. Nat. 20(2):225-229.

Two female *Oxyopes scalaris* were observed feeding on male and female *Ips pini* bark beetles while guarding egg sacs on ponderosa pine in Arizona. A cadaver of a male *I. pini* was found ensnared in the web of a female *Theridion goodnightorum*.

MASSEY, CALVIN L., AND NOEL D. WYGANT.
1973.

Woodpeckers: Most important predators of the spruce beetle.

Colo. Field Ornithol. No. 16, p. 4-8.

Northern three-toed, Hairy, and Downy woodpeckers have destroyed as much as 75 percent of the beetle population in spruce beetle outbreaks. Woodpecker abundance may reach 30 to 45 per acre where infested trees are numerous.

MASSEY, CALVIN L.
1974.

Biology and taxonomy of nematode parasites and associates of bark beetles in the United States.

U. S. Dep. Agric. Agric. Handb. 446, 233 p.

Includes descriptions of 32 parasites and 112 associates, many of which are new to science. For the most part, life histories of the parasites are synchronized with their host. Adult parasites are usually produced in adult beetles. Many of the parasites sterilize their host. Further research is indicated to explore several approaches to biological control of bark beetles with nematodes.

MC KNIGHT, M. E.
1973.

Parasitoids reared from collections of *Rhyacionia bushnellii* from the Great Plains (Lepidoptera: Olethreutidae).

Insect Parasites, Predators

J. Kans. Entomol. Soc. 46:139-143.

Collections of larvae and pupae of *Rhyacionia bushnelli* Busck, the western pine tip moth, from various locations in Kansas, Nebraska, South Dakota, North Dakota, and Montana yielded 24 species of parasitoids in seven families of Hymenoptera and one family of Diptera.

MC KNIGHT, M. E.

1974.

Parasitoids of the western spruce budworm in Colorado.

Environ. Entomol. 3:186-187.

Twenty-eight species of primary parasitoids were collected during study of a major budworm outbreak that developed in the late 1950's and collapsed in the early 1960's. Parasitoids were of little importance in determining budworm survival in any age interval except pupa.

TOLIVER, MICHAEL E., AND DANIEL T. JENNINGS.

1975.

Food habits of *Sceloporus undulatus tristichus* Cope (Squamata: Iguanidae) in Arizona.

Southwest. Nat. 20:1-11.

Analyses of 86 stomachs indicate Isoptera are the major food items in late July and August. Predation on the southwestern pine tip moth is apparently insignificant. Four families of insects and ten families of spiders are reported as prey of *Sceloporus* for the first time.

SCHMID, J. M., J. C. MITCHELL, AND M. H. SCHROEDER.*

1973.

Bark beetle emergence cages modified for use as pit traps.

USDA For. Serv. Res. Note RM-244, 2 p.

Bark beetle emergence cages collect numerous ground dwelling insects when modified for use as pit traps.

SCHROEDER, MAX H.*, JAMES C. MITCHELL, AND J. M. SCHMID.

1975.

Modifications in the Malaise insect trap.

USDA For. Serv. Res. Note RM-299, 2 p.

Bronze screen funnel replaces plastic, and a metal frame replaces wood to make the Malaise insect trap more durable and rigid on windswept rangelands.

TAGESTAD, A. D.

1974.

A technique for mounting microlepidoptera.

J. Kans. Entomol. 47:26-30.

An efficient method for mounting small moths is described and illustrated. Styrofoam mounting blocks, cover glass, and acetate circles and strips are utilized.

Experimental Techniques, Equipment

ACCIAVATTI, ROBERT E.,* AND DANIEL T. JENNINGS.

1976.

Locating western spruce budworm egg masses with ultraviolet light.

USDA For. Serv. Res. Note RM-313, 3 p.

Egg masses on 24-inch Douglas-fir branches were located more quickly and accurately with longwave ultraviolet light than with visible light. Most egg masses missed under ultraviolet light were old and parasitized, while almost half of those missed under visible light were new.

FRYE, R. H.,* AND J. M. SCHMID.

1972.

Polypropylene jars improve performance of bark beetle emergence cages.

J. Econ. Entomol. 65:931.

Freezing water won't break polypropylene jars.

JENNINGS, DANIEL T.

1973.

An emergence cage for soil-pupating *Rhyacionia* spp.

USDA For. Serv. Res. Note RM-250, 4 p.

Describes materials, construction, and installation of an inexpensive cage successfully used to determine adult emergence periods for the southwestern pine tip moth, *Rhyacionia neomexicana* (Dyar). The cage can be used to trap other soil-pupating *Rhyacionia* spp.

JENNINGS, DANIEL T.

1975.

A sex-lure trap for *Rhyacionia* tip moths.

USDA For. Serv. Res. Note RM-284, 4 p.

An inexpensive sex-lure trap is constructed from an ice-cream carton and a board supported on a stake. Caged virgin female moths lure low-flying males to the trap.

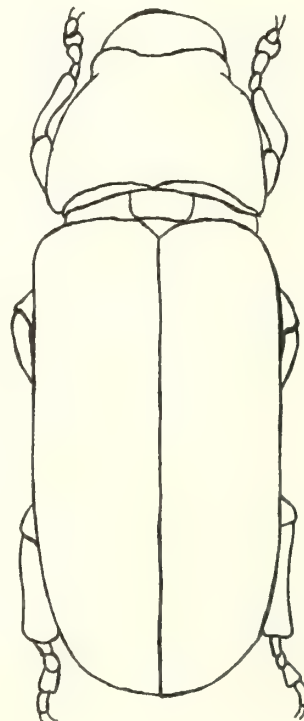
JENNINGS, DANIEL T., AND ROBERT E. ACCIAVATTI.*

1975.

Sexing large aspen tortrix pupae.

USDA For. Serv. Res. Note RM-298, 2 p.

Large aspen tortrix pupae can be sexed by the position and configuration of the genital pore.



FOREST MANAGEMENT

*Private, State or Federal cooperator

Tree Species, Dendrology

JONES, JOHN R., AND DONALD C. MARKSTROM.
1973.

Aspen...an American wood.

U. S. Dep. Agric. FS-217, 8 p.

The most widely distributed tree species in North America, aspen is one of our softer and lighter commercial hardwoods. Largest volumes are used in pulp products. Wood is light colored, straight grained, and finely textured.

MARKSTROM, DONALD C., AND JOHN R. JONES.
1975.

White fir...an American wood.

U.S. Dep. Agric. FS-237, 9 p.

Describes the distribution and growth characteristics of the trees, and the production, properties, and uses of the wood of the six species and two varieties generally referred to as white fir: Pacific silver, white, grand, subalpine, corkbark, California red, Shasta red, and noble.

Tree Physiology, Silvics, Plant Communities

ALEXANDER, ROBERT R., AND W. D. SHEPPARD
(SHEPPERD)

1974.

***Ceratonia siliqua* (L.). Carob.**

p. 303-304. *In* Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

ALEXANDER, ROBERT R.

1974.

***Ginkgo biloba* L. Ginkgo.**

p. 429-430. *In* Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

COCHRAN, P. H.,* AND CARL M. BERNTSEN.

1973.

Tolerance of lodgepole and ponderosa pine seedlings to low night temperatures.

For. Sci. 19:272-280.

Results of growth chamber and field measurements in Oregon support the hypothesis that 'frost pocket' distribution of lodgepole pine in a mosaic with ponderosa pine stands is partly due to greater tolerance of young lodgepole seedlings to low night temperatures. [Request for reprint may be sent to Pacific Northwest Forest and Range Exp. Stn., P. O. Box 3141, Portland, Oreg. 97208.]

FFOLIOTT, PETER F.,* AND WARREN P. CLARY.

1972.

A selected and annotated bibliography of understory-overstory vegetation relationships.

Ariz. Agric. Exp. Stn. Tech. Bull. 198, 33 p.

The bibliography is organized by five overstory categories:

coniferous, deciduous, mixed coniferous-deciduous, shrub, and other. Includes an author index.

JOHNSEN, THOMAS N., JR.,* AND ROBERT A. (R.) ALEXANDER.

1974.

***Juniperus* L. Juniper.**

p. 460-469. *In* Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

JONES, JOHN R.

1972.

Moisture stresses in Arizona mixed conifer seedlings.

USDA For. Serv. Res. Pap. RM-86, 8 p.

Seedlings less than about 6 inches tall had higher stresses than larger trees. Nighttime recovery was complete. There was no increasing trend of stresses through the dry season; variability seemed a function of day-to-day weather differences. Species differences were small but significant.

JONES, JOHN R.

1974.

Aspen sucker growing from an Engelmann spruce stump.

USDA For. Serv. Res. Note RM-264, 2 p.

A root from an adjacent aspen entered the base of a spruce stump, grew upward nearly to the top, then back down into the soil on the other side. This path suggests that some mechanism tends to keep lateral aspen roots near the substrate surface. The root later produced a sucker through the top of the stump.

JONES, JOHN R., AND WILLIS J. RIETVELD.

1974.

Occurrence of *Picea pungens* (Pinaceae) near Flagstaff, Arizona.

Southwest. Nat. 19:334-335.

Reports blue spruce in three locations at least 100 km from any previous locations reported, and speculates on possible origins of these stands.

JONES, JOHN R., AND DAVID P. TRUJILLO.

1975.

Height-growth comparisons of some quaking aspen clones in Arizona.

USDA For. Serv. Res. Note RM-282, 4 p.

Three of five pairs of adjacent clones in 70-yr-old aspen stands were of significantly different height. The differences developed in early life. In one pair the difference was large, suggesting possibilities of selecting clonal material for planting.

NOBLE, DANIEL L.

1972.

Effects of soil type and watering on germination, survival, and growth of Engelmann spruce: A greenhouse study.

USDA For. Serv. Res. Note RM-216, 4 p.

Germination was not affected by different soils but increased as amount of water applied monthly increased from none to 1.5 inches. Survival was influenced by soils as well as amount of water received. Top height and total plant dry weight were not significantly related to either soils or watering treatments.

NOBLE, DANIEL L.

1973.

Age of Engelmann spruce seedlings affects ability to

withstand low temperature: A greenhouse study.
USDA For. Serv. Res. Note RM-232, 4 p.

Spruce seedlings were exposed to 5, 15, and 25 F. cold treatments at six development stages--2 weeks through 12 weeks at 2-week intervals. All seedlings survived the 25 F., but no seedlings survived 5 F. At 15 F. few seedlings 2 to 8 weeks old survived, but most seedlings 10 to 12 weeks old survived. No correlation could be found between cold resistance and moisture content.

NOBLE, DANIEL L.

1973.

Engelmann spruce seedling roots reach depth of 3 to 4 inches their first season.

USDA For. Serv. Res. Note RM-241, 3 p.

First-year Engelmann spruce seedlings have an average rooting depth of 3.4 inches, 11 branch roots, and a total root length of 5 inches. Seedlings were field-grown on scarified shaded seedbeds in the central Rocky Mountains, Colorado.

READ, RALPH A.

1974.

***Phellodendron amurense* Rupr. Amur corktree.**

p. 578-579. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

READ, RALPH A.

1974.

***Sapindus drummondii* Hook. and Arn. Western soapberry.**

p. 758-759. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

READ, RALPH A., AND R. L. BARNES.*

1974.

Morus L. Mulberry.

p. 544-547. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

RIETVELD, W. J.

1976.

Hydrophilic polymer reduces germination of ponderosa pine in seed spots.

Tree Plant. Notes 27(1):18-19, 21.

Ponderosa pine seedlings emerged later and in fewer numbers when a hydrophilic polymer was added to seed spots, but survival and height growth of seedlings were unaffected.

RONCO, FRANK.

1972.

Overwinter food reserves of potted Engelmann spruce seedlings.

Can. J. For. Res. 2:489-492.

Lipid, protein, and hemicellulose varied little during the winter. Results did not appear to support an hypothesis that mortality of planted seedlings was caused by overwinter depletion of food reserves.

RONCO, FRANK.

1972.

Solarization--a high elevation problem.

West. Reforestation Coord. Comm. [Seattle, Wash., Dec. 1972] Annu. Meet. 1972:112-115. West. For. Conserv. Assoc., Portland, Oreg.

Photosynthesis may be inhibited by extremely high light intensity. This solarization phenomenon is probably the primary

cause of death in Engelmann spruce plantations in the central Rockies. Shade during the first few critical years makes a dramatic difference in seedling color and survival.

RONCO, FRANK.

1973.

Food reserves of Engelmann spruce planting stock.

For. Sci. 19:213-219.

Transplanting reduced dry weight whether seedlings were transplanted in nursery or holding beds. Carbohydrates and hemicelluloses were reduced by transplanting, lipids increased, proteins were not affected. Survival of field-planted trees was not correlated with food reserves.

RONCO, FRANK.

1975.

Diagnosis: 'sunburned' trees.

J. For. 73:31-35.

Failure of Engelmann spruce seedlings to survive when planted in the open at high elevations is apparently due to solarization: intense light inhibits photosynthesis and may subsequently cause death. Successful operational planting techniques are discussed, based on research which indicates that solarization can be eliminated simply by shading.

RUDOLF, PAUL O.,* AND PAUL E. SLABAUGH.

1974.

Syringa L. Lilac.

p. 791-793. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

SCHMID, J. M., AND T. E. HINDS.

1974.

Development of spruce-fir stands following spruce beetle outbreaks.

USDA For. Serv. Res. Pap. RM-131, 16 p.

Seedling regeneration was generally adequate except in heavily logged areas, although seedlings were often damaged, apparently by animals. Species composition was dramatically altered in favor of fir in the unlogged spruce-fir type. In the overstory, fir may predominate for many years, but eventually the spruce will replace it.

TINUS, RICHARD W.

1972.

Carbon dioxide enriched atmosphere speeds growth of ponderosa pine and blue spruce seedlings.

Tree Planters' Notes 23(1):12-15.

Height, caliper, and number of side branches of 1-year-old seedlings grown under 1200 ppm carbon dioxide were greater than for seedlings grown under ambient air. Fresh and dry weights were strikingly greater.

TINUS, RICHARD W.

1974.

Impact of the carbon dioxide requirement on plant water use.

Agric. Meteorol. 14(1/2):99-112.

Land plants lose much water because they must expose photosynthetic tissue to air to obtain carbon dioxide. Succulents which absorb carbon dioxide at night and C-4 plants which lack photorespiration are more efficient. Antitranspirants may reduce water loss. Perhaps water-use efficiency can be increased by breeding.

TINUS, RICHARD W.

1974.

Response of several tree species to day and night temperature.

North Am. For. Biol. Workshop [Fort Collins, Colo., Sept. 1974] Proc. 3:365.

In general, growth of seedlings of Scotch and ponderosa pines,

eastern redcedar, Rocky Mountain juniper, blue spruce, and bur oak was more sensitive to day than to night temperatures.

TINUS, RICHARD W.

1975.

Growth retardants control development of deciduous nursery stock.

Tree Plant. Notes 26(1):5-7.

Two growth retardants were tested for nursery use to control size of five hardwood species. Alar slowed growth of lilac and cotoneaster. SloGro stopped growth of Siberian elm, slowed growth of honeysuckle and cotoneaster. Chemicals were less effective than undercutting on green ash.

VAN DEUSEN, JAMES L., AND LAWRENCE D. BEAGLE.

1973.

Judging ripeness of seeds in Black Hills ponderosa pine cones.

USDA For. Serv. Res. Note RM-235, 4 p.

Buoyancy of cones in water is a good indicator of cone and seed ripeness. When more than half of the cones in a sample from several trees will float, cones in that vicinity should yield a satisfactory number of viable seeds. Frequent checks on specific gravity are needed from mid-August on, since ripening proceeds rapidly then.

WIRSING, JOHN M.,* AND ROBERT R. ALEXANDER.

1975.

Forest habitat types on the Medicine Bow National Forest, southeastern Wyoming: Preliminary report.

USDA For. Serv. Gen. Tech. Rep. RM-12, 12 p.

A vegetation classification based on concepts and methods developed by Daubenmire was used to identify five habitat types and their related phases. A key to identify the habitat types and management implications associated with them are provided.

Genetics, Tree Improvement

CUNNINGHAM, RICHARD A.

1972.

Development of Siberian and Dahurian larches after 10 years in North Dakota.

USDA For. Serv. Res. Note RM-209, 4 p.

Trees were grown from three Siberian larch, one Dahurian larch, and two hybrid larch seed sources. Two Siberian origins may be suitable for windbreak plantings in the Northern Great Plains.

CUNNINGHAM, RICHARD A.

1973.

Scotch pine for the Northern Great Plains.

USDA For. Serv. Res. Pap. RM-114, 12 p.

A provenance test of 49 origins of Scotch pine (*Pinus sylvestris* L.) from eastern Europe, Russia, and Siberia was established at three locations in North Dakota and one in Nebraska. After 10 years (7 in Nebraska), trees from 50 to 55 degrees latitude and 20 to 40 degrees longitude survived best, were taller, and had greener winter foliage. Several provenances appear to be well suited for planting in shelterbelts and for Christmas tree culture.

CUNNINGHAM, RICHARD A.

1975.

Provisional tree and shrub seed zones for the Great Plains.

USDA For. Serv. Res. Pap. RM-150, 15 p.

The Great Plains Region was subdivided into 86 seed collection zones on the basis of soil, topography, water, and climate. Seed should be collected from the zone to be planted, or, if unavailable, from a zone having similar soil and climate. Future provenance test results will be used to determine any need for adjustments in zone boundaries.

DENEKE, FREDERICK J.,* AND RALPH A. READ.

1975.

Early survival and growth of ponderosa pine provenances in east-central Kansas.

USDA For. Serv. Res. Note RM-297, 4 p.

A provenance test of 78 sources of *Pinus ponderosa* was established in 1968 near Junction City. Progeny from the Pacific Northwest and the southern Rocky Mountains performed poorly. Progeny from the northeastern range of the species performed best.

FARNSWORTH, D. H.,* G. E. GATHERUM,* J. J. JOKELA,* H. B. KRIEBEL,* D. T. LESTER,* C. MERRITT,* S. S. PAULEY,* R. A. READ, R. L. SAIDAK,* AND J. W. WRIGHT.*

1972.

Geographic variation in Japanese larch in north central United States plantations.

Silvae Genetica 21:139-147.

Differences in growth rate among seed origins were large, whereas differences in other traits were of little practical significance. Variation in some traits followed a weak geographic pattern, trees from Mts. Asama and Nantai being most exceptional.

READ, RALPH A.

1973.

Seed origins of Scotch pine for Christmas trees in Nebraska.

Am. Christmas Tree J. 17(2):21-26.

Seedlings from 36 origins, primarily from throughout Europe, varied in growth rate, form, and color. Best origins for Christmas tree color in Nebraska are from southern France, Spain, and Turkey. A Scottish origin is recommended for overall desirable characteristics of growth, color, and form.

SPRACKLING, JOHN A., AND RALPH A. READ.

1974.

Jack pine provenance study in eastern Nebraska.

Cent. States For. Tree Improv. Conf. [Ames, Iowa, Oct. 1974] Proc. 9:85-94.

Printed as USDA Forest Service Research Paper RM-143.

SPRACKLING, JOHN A., AND RALPH A. READ.

1975.

Jack pine provenance study in eastern Nebraska.

USDA For. Serv. Res. Pap. RM-143, 8 p.

A 9-year provenance test, with 28 origins, indicated that height, form, cone production, and needle length of southern origins exceeded northern origins. Fast-growing origins developed dense, compact, well-shaped crowns because of the multinodal growth characteristic of jack pine. An Ontario origin is recommended for plantings in Nebraska.

SPRACKLING, JOHN A., AND RALPH A. READ.

1975.

Red pine provenance study in eastern Nebraska.

USDA For. Serv. Res. Pap. RM-144, 7 p.

An 11-year provenance test, with 54 rangewide origins, revealed that heights and growth rates differed significantly among origins, but tree form, needle length, and foliage color were uniform. No geographic patterns of variation were identifiable. A fast-growing Quebec origin is recommended for windbreak and landscape plantings.

TINUS, RICHARD W.

1974.

Grafting ponderosa pine scions on the parent root system.

USDA For. Serv. Res. Note RM-263, 2 p.

Reproductive success is much higher than by direct rooting, and is better distributed over the parent population.

VAN DEUSEN, JAMES L.

1974.

Five-year results of a ponderosa pine provenance study in the Black Hills.

USDA For. Serv. Res. Note RM-278, 4 p.

Data from progeny representing 75 provenances of natural stands in the Great Plains and Northern Rockies showed that trees from no other provenance survived significantly better or grew significantly taller than trees from the Black Hills.

VAN HAVERBEKE, DAVID F., WALTER T. BAGLEY,* AND ELLSWORTH H. BENSON.*

1973.

Breeding a better Christmas tree.

Nebr. Farm, Ranch and Home Q. 20(3):2-4.

Scots pines from seeds from 36 sources in Europe and Asia were planted in eastern Nebraska. Cuttings from trees with best Christmas tree characteristics are grafted onto other seedlings, then intensively managed to develop a seed orchard. Improved seeds should be available in 10 to 15 years.

VAN HAVERBEKE, DAVID F.

1974.

A Scots pine clonal seed orchard of provenance origin.

Cent. States For. Tree Improv. Conf. [Ames, Iowa, Oct. 1974] Proc. 9:62-70.

Scions from Scots pines with desirable Christmas tree characteristics were selected from a 36-origin, 7-year-old provenance plantation in Nebraska, and grafted onto potted Scots pine stock. A 1,000-tree clonal seed orchard has been established containing one ramet each of 42 selected ortets.

WRIGHT, JONATHAN W.,* RALPH A. READ, DONALD T. LESTER,* CLAIR MERRITT,* AND CARL MOHN.*

1972.

Geographic variation in red pine: 11-year data from the North Central States.

Silvae Genet. 21:205-210.

Seeds from 91 natural stands and three plantations were tested in eight north-central localities. The 10 fastest growing seedlots grew rapidly at nearly all sites. Thus one set of criteria may suffice for seed procurement and seed orchard development for all the region except the extreme south.

Forest Measurements (Mensuration)

ALEXANDER, ROBERT R., WAYNE D. SHEPPERD, AND CARLETON B. EDMINSTER.

1975.

Yield tables for managed even-aged stands of spruce-fir in the central Rocky Mountains.

USDA For. Serv. Res. Pap. RM-134, 20 p.

Presents procedures for deriving yield tables for managed stands of spruce-fir from data obtained on temporary plots, and the computer programs developed by Myers (1971).

AVERY, CHARLES C.,* FREDERIC R. LARSON, AND GILBERT H. SCHUBERT.

1976.

Fifty-year records of virgin stand development in southwestern ponderosa pine.

USDA For. Serv. Gen. Tech. Rep. RM-22, 71 p.

Ten periodic inventories of an unburned virgin tract of more than 3,000 trees by individual tree records, 2.5-acre subplot summaries of basal area and tree census data, and composite stand tables which display census data, mortality data, and causes, net periodic basal area, volume, and diameter growth.

BEAGLE, LAWRENCE D.

1974.

Cubic-foot volume tables for white spruce in the Black Hills.

USDA For. Serv. Res. Note RM-266, 2 p.

Two tables give volumes in total and merchantable cubic feet. Total volumes include all stemwood from ground line to tip of

tree, while merchantable volumes include stemwood from a 1-foot stump to a 4-inch d.i.b. top.

EDMINSTER, CARLETON B., AND FRANK G. HAWKSWORTH.

1976.

User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe.

USDA For. Serv. Gen. Tech. Rep. RM-23, 8 p.

Describes procedures for application of computer program SWYLD2 (Myers and others, USDA For. Serv. Res. Pap. RM-163, 1976) for yield simulation of even-aged and two-storied stands of southwestern ponderosa pine, including the effects of dwarf mistletoe. SWYLD2 supersedes SWYLD program, published in USDA For. Serv. Res. Pap. RM-87, 1972.

HAWKSWORTH, FRANK G., AND CLIFFORD A. MYERS.

1973.

Procedures for using yield simulation programs for dwarf mistletoe-infested lodgepole and ponderosa pine stands.

USDA For. Serv. Res. Note RM-237, 4 p.

Describes procedures for application of two recently published computer programs for yield simulation of dwarf-mistletoe-infested stands: LPMIST for lodgepole pine in the central Rocky Mountains and SWYLD for ponderosa pine in the Southwest.

MYERS, CLIFFORD A.

1972.

Volume, taper, and related tables for southwestern ponderosa pine.

U. S. For. Serv. Res. Pap. RM-2, 24 p. (Rev.)

Presents volume tables, taper tables, and the distribution of tree volumes among the logs of saw log trees. Volumes are in total cubic feet and cubic feet to a variable top. Tree heights are in feet and numbers of logs.

MYERS, CLIFFORD A., AND ROBERT R. ALEXANDER.

1972.

Bark thickness and past diameters of Engelmann spruce in Colorado and Wyoming.

USDA For. Serv. Res. Note RM-217, 2 p.

Past diameter can be estimated from present diameters and radial wood growth for any desired period. Equation constants account for any periodic change in bark thickness.

MYERS, CLIFFORD A., AND CARLETON B. EDMINSTER.

1972.

Volume tables and point-sampling factors for Engelmann spruce in Colorado and Wyoming.

USDA For. Serv. Res. Pap. RM-95, 23 p.

Volumes are in total cubic feet and cubic feet to a 4.0-inch top, board feet Scribner Rule to 6-inch and 8-inch tops, and board feet International 1/4-inch Rule to 6-inch and 8-inch tops. Tree heights are in feet and numbers of logs.

MYERS, CLIFFORD A., FRANK G. HAWKSWORTH, AND PAUL C. LIGHTLE.

1972.

Simulating yields of southwestern ponderosa pine stands, including effects of dwarf mistletoe.

USDA For. Serv. Res. Pap. RM-87, 16 p.

Presents a procedure for computation of yield tables for diseased even-aged stands. Control variables include stand age at time of initial infection and at initial thinning, stocking goals, frequency of thinning, and regeneration system. Stand conditions and severity of infestation change with time and in response to intermediate cuttings.

MYERS, CLIFFORD A., AND CARLETON B. EDMINSTER.

1974.

Conversion of tree-volume equations to the metric system.

USDA For. Serv. Res. Note RM-261, 2 p.

Presents factors for converting volume equations from U.S. Customary to metric units.

MYERS, CLIFFORD A., CARLETON B. EDMINSTER, AND FRANK G. HAWKSWORTH.

1976.

SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe.

USDA For. Serv. Res. Pap. RM-163, 25 p.

Possible alternatives for computing yield tables include: even-aged or two-storied, healthy or diseased, and managed or unmanaged stand densities. Stand conditions and severity of dwarf mistletoe change with time and in response to intermediate cuttings. Supersedes Res. Pap. RM-87. A concise user's guide is available as Gen. Tech. Rep. RM-23.

SPRACKLING, JOHN A.

1973.

Soil-topographic site index for Engelmann spruce on granitic soils in northern Colorado and southern Wyoming.

USDA For. Serv. Res. Note RM-239, 4 p.

Site index of Engelmann spruce can be estimated from soil depth to the C horizon and elevation. Predictions should be confined to potential spruce-fir sites on granitic soils in northern Colorado and southern Wyoming.

VAN DEUSEN, JAMES L.

1975.

Estimating breast height diameters from stump diameters for Black Hills ponderosa pine.

USDA For. Serv. Res. Note RM-283, 3 p.

Presents tables and equations to estimate diameter at breast height, outside bark, from inside and outside bark diameters of stumps 6 inches and 1 foot high.

Forest Management Planning

COLORADO STATE UNIVERSITY, COLLEGE OF FORESTRY AND NATURAL RESOURCES.

1972.

Pilot test of program TEVAP for preparation of timber management plans and simulation of a regional data center for decision making in forest management, final report, September 30, 1972.

Colo. State Univ., Coll. For. Nat. Resour., Dep. For. Wood Sci., Fort Collins, Colo., 65 p.

The test was performed by a team consisting of three groups: research, users, and computer services. Results indicate that the programs form a valuable basis for timber management decisionmaking at the National Forest level, and that a regional data center is warranted if management plans are to be updated frequently.

EDWARDS, BRUCE M.,* GARY E. METCALF,* AND W. E. FRAYER.*

1973.

Computer-produced timber management plans: An evaluation of program TEVAP.

USDA For. Serv. Res. Note RM-251, 4 p.

TEVAP (Timber Evaluation And Planning), a computerized timber management planning system, was tested over a 2-year period on the Black Hills National Forest. The system's utility in the decisionmaking process was demonstrated for both broad and local areas.

FFOLLIOTT, PETER F., AND DAVID P. WORLEY.
1973.

Forest stocking equations: Their development and application.

USDA For. Serv. Res. Pap. RM-102, 8 p.

Equations relating proportions of a forest stocked to minimum basal area levels corresponding to each basal area factor used in an inventory can be defined by regression analysis. Equations can be used to help evaluate land treatment potential, determine treatment feasibility, and set operating priorities.

MYERS, CLIFFORD A.

1973.

Simulating changes in even-aged timber stands.

USDA For. Serv. Res. Pap. RM-109, 47 p.

A FORTRAN IV computer program simulates timber management by shelterwood, seed tree, or clearcutting systems. Tree growth, intermediate and regeneration cuts, planting, and catastrophic losses are among changes computed. Annual and periodic costs and returns, analysis of rate earned, and other volumes and values are printed. Supersedes Res. Pap. RM-42.

MYERS, CLIFFORD A.

1974.

Computerized preparation of timber management plans: TEVAP2.

USDA For. Serv. Res. Pap. RM-115, 72 p.

Presents computer programs, written in FORTRAN IV, for analysis of inventory data, and computation of actual and optimum growing stocks and allowable cuts, and other values needed for forest management planning. Computed volumes and areas are summarized in a timber management plan. Effects of cultural operations and other changes are accounted for in computation of both actual and optimum conditions.

Silvicultural Systems

ALEXANDER, ROBERT R.

1972.

Initial partial cutting in old-growth spruce-fir.

USDA For. Serv. Res. Pap. RM-76, 10 p. (Rev.)

Interim guidelines are provided to aid the forest manager in developing alternatives to clearcutting in old-growth spruce-fir forests in Colorado and southern Wyoming. Included are practices for different conditions that should maintain continuous high forest cover to preserve the forest landscape, and that may also be used with small cleared openings to integrate timber production with other key uses. For convenient field use, a smaller, brief version entitled 'Initial partial cutting in old-growth spruce-fir: a field guide' is available as USDA Forest Serv. Res. Pap. RM-76A.

ALEXANDER, ROBERT R.

1972.

Partial cutting practices in old-growth lodgepole pine.

USDA For. Serv. Res. Pap. RM-92, 16 p.

Guidelines are provided to aid the forest manager in developing partial cutting practices to maintain continuous forest cover in travel influence zones, and in areas of high recreational values or outstanding scenic beauty. These guidelines consider stand conditions, windfall risk situations, and insect and disease problems. These cutting practices also may be used in combination with small cleared openings to create the kinds of stands desirable for increased water yields, improvement of wildlife habitat, and to integrate timber production with other uses. On areas where timber production is the primary objective, clearcutting in small, dispersed units is the recommended method of harvesting trees. For convenient field use, a smaller, brief version, 'Partial cutting practices in old-growth lodgepole pine: a field guide' is available as USDA Forest Serv. Res. Pap. RM-92A.

ALEXANDER, ROBERT R.
1973.

Partial cutting in old-growth spruce-fir.
USDA For. Serv. Res. Pap. RM-110, 16 p.

Guidelines aid the forest manager in developing partial cutting practices to convert old-growth spruce-fir forests into managed stands, while maintaining continuous forest cover. These practices can be used in combination with small cleared openings to increase water yields, improve wildlife habitat, and integrate timber production with other uses. Supersedes Res. Pap. RM-76.

ALEXANDER, ROBERT R.
1974.

Silviculture of central and southern Rocky Mountain forests: A summary of the status of our knowledge by timber types.

USDA For. Serv. Res. Pap. RM-120, 36 p.

Summarizes a series of comprehensive reports on the silviculture of lodgepole pine, ponderosa pine, mixed conifer, and spruce-fir timber types. Includes what is known, what can be recommended, and what additional information is needed for each timber type. (Available from Superintendent of Documents, Stock No. GPO 0101-00368.)

ALEXANDER, ROBERT R.
1974.

Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-121, 88 p.

The ecology and resource of the Rocky Mountain subalpine forests in Wyoming, Colorado, and New Mexico are briefly described, followed by in-depth reviews of the spruce-fir type and lodgepole pine type. The relevant literature is included, along with unpublished research, observations, and experience. Research needs are considered as well as what is already known. (Available from Superintendent of Documents, Stock No. GPO 0101-00381.)

ALEXANDER, ROBERT R.
1975.

Partial cutting in old-growth lodgepole pine.
USDA For. Serv. Res. Pap. RM-136, 17 p.

Guidelines are provided for partial cutting where continuous forest cover should be maintained. Partial cutting in combination with small cleared openings can increase water yields, improve wildlife habitat, and integrate timber production with other uses. Where timber production is the primary objective, clearcutting in small, dispersed units is recommended.

BOLDT, CHARLES E.
1973.

Central and southern Rocky Mountain types: Black Hills ponderosa pine.
p. 52-53. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically feasible for managing Black Hills ponderosa pine. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

BOLDT, CHARLES E., AND JAMES L. VAN DEUSEN.
1974.

Silviculture of ponderosa pine in the Black Hills: Status of our knowledge.

USDA For. Serv. Res. Pap. RM-124, 45 p.

This Paper, intended as a guide for professional foresters, describes major silvicultural conditions likely to be encountered in the Black Hills, reasonable treatment options, and probable results and implications of these treatments. It also describes silvical characteristics and behavior of Black Hills ponderosa

pine, and a variety of proven silvicultural tools. (Available from Superintendent of Documents, Stock No. GPO 0101-00384.)

JONES, JOHN R.
1973.

Central and southern Rocky Mountain types: Rocky Mountain aspen.
p. 49-51. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically feasible for managing Rocky Mountain aspen. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

JONES, JOHN R.
1973.

Central and southern Rocky Mountain types: Southwestern mixed conifers.
p. 47-49. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically feasible for managing southwestern mixed conifers. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

JONES, JOHN R.
1974.

Silviculture of southwestern mixed conifers and aspen: The status of our knowledge.
USDA For. Serv. Res. Pap. RM-122, 44 p.

Brings together in one document a discussion of the relevant literature, observations, experience, and unpublished research on the ecology and silviculture of mixed conifers in the interior Southwest. Research needs are also considered. (Available from Superintendent of Documents, Stock No. GPO 0101-00377.)

LOTAN, JAMES E.,* AND ROBERT R. ALEXANDER.
1973.

Northern Rocky Mountain types: Lodgepole pine.
p. 42-44. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric. Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically feasible for managing lodgepole pine. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

SCHMIDT, WYMAN C.,* CHARLES A. WELLNER,* AND ROBERT R. ALEXANDER.
1973.

Northern Rocky Mountain types: Engelmann spruce-subalpine fir.
p. 40-42. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically feasible for managing Engelmann spruce-subalpine fir. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

SCHUBERT, GILBERT H.
1973.

Central and southern Rocky Mountain types: Southwestern ponderosa pine.
p. 45-46. *In Silvicultural systems for the major forest types of the United States.* U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Summarizes the silvicultural systems that appear biologically

feasible for managing southwestern ponderosa pine. Supporting information is given on extent and characteristics of the type, cultural requirements of component species, and biological factors that control the choice of silvicultural options.

SCHUBERT, GILBERT H.

1974.

Silviculture of southwestern ponderosa pine: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-123, 71 p.

Economic value, impacts on other uses, and the timber resource are discussed first, followed by ecological background, site quality, growth and yield, and silviculture and management. Relevant literature is discussed along with observations, experience, and results of unpublished research. Research needs are also considered. (Available from Superintendent of Documents, Stock No. GPO 0101-00380.)

SCHUBERT, GILBERT H.

1976.

Silvicultural practices for intensified forest management.

p. 37-54. *In* **Trees--The renewable resource. Proc. Rocky Mt. For. Ind. Conf. [Tucson, Ariz., Mar. 1976].**

We need to intensify management efforts along three main lines: (1) reduce the time lost in reforesting logged and burned areas, (2) shorten the time required to get replacement trees to commercial sizes by early precommercial thinning, and (3) maintain the desired growth rate throughout the tree's life by properly scheduled intermediate cuts.

Reforestation — Natural Regeneration

JONES, JOHN R., AND DAVID P. TRUJILLO.

1975.

Development of some young aspen stands in Arizona.

USDA For. Serv. Res. Pap. RM-151, 11 p.

A substantial apparent range of genotypes and sites was sampled in aspen stands on a 23-year-old mixed conifer burn. All plots were heavily stocked with aspen suckers by the end of the third summer. Stocking as well as height differed among clones growing together on the same site.

JONES, JOHN R.

1975.

Regeneration on an aspen clearcut in Arizona.

USDA For. Serv. Res. Note RM-285, 8 p.

After four growing seasons mil-acre stocking on a 5-acre clearcut was 98 percent. The tallest on any plot was 17.4 feet. Stocking density was irregular. Thinly stocked spots seemed largely associated with slash concentrations, haul roads, and main skid trails.

RIETVELD, W. J.

1975.

Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine.

USDA For. Serv. Res. Pap. RM-153, 15 p.

Extracts of Arizona fescue and mountain muhly significantly reduced germination of ponderosa pine seeds, and retarded speed of elongation and mean radicle length. Three possible routes of release of the inhibitor were investigated: (1) leaching from live foliage, (2) root exudation, and (3) overwinter leaching from dead residues.

Reforestation—Artificial Regeneration, Nurseries, and Greenhouses

HIATT, HARVEY A., AND RICHARD W. TINUS.

1974.

Container shape controls root system configuration of ponderosa pine.

p. 194-196. *In* **North Am. Containerized For. Tree Seedling Symp. [Denver, Colo., Aug. 1974] Proc. Great Plains Agric. Counc. Publ. 68, 458 p.**

Ponderosa pines grown in different containers showed some recovery from root coiling after outplanting. Trees grown in containers with no walls had no more coiling than trees grown from seed in place, and seedlings grown in containers with vertical grooves had less coiling than ones grown in smooth-walled containers.

JOHNSEN, THOMAS N., JR.,* GILBERT H. SCHUBERT, AND DEWEY P. ALMAS.*

1973.

Rehabilitation of forest land: The Rocky Mountain-Intermountain Region.

J. For. 71:144-147.

Underlying problem aspects of competition include better: knowledge and use of site evaluations, understanding of basic plant needs and competition, and site-treatment prescriptions.

JONES, JOHN R.

1974.

A spot seeding trial with southwestern white pine and blue spruce.

USDA For. Serv. Res. Note RM-265, 7 p.

Despite abundant germination, favorable slope aspects, absence of heavy herbaceous competition, good cold air drainage, and initial rodent reduction, few seedlings survived to the middle of the third summer. Major known causes of death were frost heaving, predation, and soil burial.

JONES, JOHN R.

1975.

A southwestern mixed conifer plantation--case history and observations.

USDA For. Serv. Res. Pap. RM-148, 8 p.

Ponderosa pine, Douglas-fir, and blue spruce were planted on clearcuttings in east-central Arizona at 9200 ft. Some markedly inferior stock survived and grew poorly. Pines on south slopes that survived a meadow mouse outbreak were vigorous. Blue spruce survived and grew well on north-facing slopes, poorly on south slopes.

RIETVELD, W. J., AND L. J. HEIDMANN.

1974.

Mulching planted ponderosa pine seedlings in Arizona gives mixed results.

USDA For. Serv. Res. Note RM-257, 3 p.

Mulching of 3-0 spring-planted ponderosa pine seedlings on difficult sites with clear and black polyethylene, petroleum-emulsion, volcanic cinders, woodchips, and dead grass sod was generally ineffective.

RIETVELD, W. J., AND L. J. HEIDMANN.

1976.

Direct seeding ponderosa pine on recent burns in Arizona.

USDA For. Serv. Res. Note RM-312, 8 p.

Results of direct seeding are extremely variable, even on favorable sites. Direct seeding recent burns, even by spot seeding, is of limited usefulness in the Southwest. The method should be reserved as a flexible tool to promptly regenerate only the best sites when planting stock is unavailable.

RONCO, FRANK.

1972.

Planting Engelmann spruce.

USDA For. Serv. Res. Pap. RM-89, 24 p.

Reforestation operations covered include storage, transportation, microsite selection, site preparation, planting, plantation protection, and recordkeeping. Physiological and

silvicultural requirements of spruces are discussed with respect to the harsh environment of the spruce-fir zone. Mattock planting and methods of providing shade are emphasized. For convenient field use, a smaller, brief version, 'Planting Engelmann spruce: a field guide' is available as USDA Forest Serv. Res. Pap. RM-89A.

SCHUBERT, GILBERT H., AND JOHN A. PITCHER.*
1973.

A provisional tree seed-zone and cone-crop rating system for Arizona and New Mexico.
USDA For. Serv. Res. Pap. RM-105, 8 p.

The forested areas were divided into 10 physiographic-climatic regions, subdivided into 5 to 9 seed collection zones. Provenance tests will determine need for adjustments. Seed for reforestation should be collected within the zone. A 10-unit classification system for rating cone crops is included.

SLABAUGH, PAUL E.

1974.

Siberian elm seedling development enhanced by wider in-row spacing.

Tree Planters' Notes 25(1):23-24.

A seeding rate that results in row densities of 15 to 20 trees per linear foot at age 2-0, while producing slightly fewer usable, will result in economies in overall production costs.

STEIN, WILLIAM I.,* PAUL E. SLABAUGH, AND A. PERRY PLUMMER.*

1974.

Harvesting, processing, and storage of fruits and seeds. p. 98-125. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Availability of viable seeds to regenerate a variety of trees and shrubs depends on use of sound biological information and proven practices. This chapter covers the concepts and practices proven sound and effective for collecting, processing, and storing small or large quantities of fruits and seeds.

STEIN, WILLIAM I.,* JERRY L. EDWARDS,* AND RICHARD W. TINUS.

1975.

Outlook for container-grown seedling use in reforestation.

J. For. 73:337-341.

The North American Containerized Forest Tree Seedling Symposium at Denver, Colorado, covered the status and technical aspects of container-grown seedling production and use. Current trends, state of knowledge, and problems to solve are covered in this overview of material appearing in the Proceedings.

TINUS, RICHARD W.

1974.

Conifer seedling nursery in a greenhouse.

J. Soil Water Conserv. 29:122-125.

A new greenhouse system for growing containerized tree seedlings avoids many problems of outdoor nurseries. In 1 year, seedlings equal in size 3- to 4-year-old nursery stock grown outdoors on the Great Plains.

TINUS, RICHARD W.

1974.

Large trees for the Rockies and Plains.

p. 112-118. In North Am. Containerized For. Tree Seedling Symp. [Denver, Colo., Aug. 1974] Proc. Great Plains Agric. Counc. Publ. 68, 458 p.

Harsh site conditions require large trees in large containers for best survival. The strategy is to grow the seedling rapidly in its optimum environment, and design the growing cycle to deliver the desired size in proper outplanting condition at a specified time. Procedure for growing several species is outlined.

TINUS, RICHARD W.

1974.

Characteristics of seedlings with high survival

potential.

p. 276-282. In North Am. Containerized For. Tree Seedling Symp. [Denver, Colo., Aug. 1974] Proc. Great Plains Agric. Counc. Publ. 68, 458 p.

To survive, species and seed source must be adapted to the site, the seedlings must be in the proper physiological state to meet the new environment, and root contact with the soil must be quickly established.

TINUS, RICHARD W., WILLIAM I. STEIN,* AND WILLIAM E. BALMER.* (EDITORS)

1974.

Proceedings of North American Containerized Forest Tree Seedling Symposium, Denver, Colo., August 26-29, 1974.

Great Plains Agric. Counc. Publ. 68, 458 p.

The status of our knowledge about how to grow containerized forest tree seedlings is summarized in 76 papers grouped under: development and objectives of containerization, seedling production in controlled environments, containers and handling systems, nursery procedures and problems, engineering container systems, field performance, container programs around the world, economics of containerized forestation, and the challenges ahead.

TINUS, RICHARD W.

1975.

Are bare root nurseries obsolete?

Int. Nurserymen's Assoc. [Missoula, Mont., Aug. 1975] Proc. n.p. [4 p.] Div. For., Dep. Nat. Resour. Conserv., Missoula, Mont.

The question is answered by comparing the performance of bare-root and containerized nurseries in meeting the requirements of tree seedlings and those who plant them.

TINUS, RICHARD W.

1975.

Container planting in the West.

Southeast. Nurserymen's Conf. [Nacogdoches, Tex., July 1974] Proc. 1974:43-47. Southeast. Area, U.S. Dep. Agric., For. Serv., Atlanta, Ga.

Production of container-grown tree seedlings is increasing rapidly, particularly along the West Coast. Economics (West Coast) and better survival under harsh conditions (Interior West) are primary reasons. Variations in operations are discussed.

TINUS, RICHARD W.

1975.

Observations and new information on greenhouse container systems.

Int. Nurserymen's Assoc. [Missoula, Mont., Aug. 1975] Proc. n.p. [10 p.] Div. For., Dep. Nat. Resour. Conserv., Missoula, Mont.

Summarizes new design and operation techniques learned from recent experiences.

TINUS, RICHARD W.

1975.

The place of container seedlings in nursery production programs.

Servicewide Conf. on Plant. Stock Prod. [Coeur d'Alene, Idaho, Sept. 1975] Proc., p. 129-138. Div. Timber Manage., U.S. Dep. Agric., For. Serv., Wash., D.C.

Container stock should be used (1) when it can save nursery costs, (2) when timing of planting is such that survival of bare-root stock would be poor, (3) when survival must be improved on harsh sites, and (4) when stock from a particular seed source is needed quickly.

Timber Stand Improvement

WOLLUM, A. G., II,* AND GILBERT H. SCHUBERT.
1975.

Effect of thinning on the foliage and forest floor properties of ponderosa pine stands.

Soil Sci. Soc. Am. Proc. 39(5):968-972.

Although the longest and heaviest needle fascicles were associated with greater thinning intensities, foliar nutrient concentrations were not significantly different among thinning regimes. Total nutrients in the forest floor were inversely proportional to degree of thinning.

Shelterbelts

CHESNIN, LEON,* AND D. F. VAN HAVERBEKE.
1972.

Feedlot waste runoff, its influence on soil chemical properties and the survival of windbreak trees.

Agron. Abstr., Am. Soc. Agron. Annu. Meet. [Miami Beach, Fla., Oct.-Nov. 1972] Div. A-5, p. 178.

A combination of adverse soil chemical properties may result from flow of feedlot wastes through windbreaks. Trees in areas subjected to runoff flow from new feedlots may die rather quickly.

READ, RALPH A.
1972.

Plan before planting tree windbreaks.

Colo. Rancher Farmer 26(2):30, 34.

In addition to physical design and selection of species, planning must include purposes of the windbreak, maintenance, and correlation with other conservation practices.

READ, RALPH A.
1975.

Tree planting trends--as indicated by distribution of species in Great Plains States.

[21 p.] In Trees, food, energy. 27th Annu. Meet. Great Plains For. Comm. [Lincoln, Nebr., June 1975] Proc. Great Plains Agric. Counc. 76, n.p. [216 p.]

Summarizes 5-year planting trends, by coniferous trees, broad-leaved trees, and shrubs, for the 10 Prairie States.

SLABAUGH, PAUL E.
1974.

Renewed cultivation revitalizes sodbound shelterbelts.

J. Soil Water Conserv. 29:81-84.

Cultivation restored vigor of four multirow shelterbelts, 12 to 17 years old, in North Dakota. Sod removal after 11 years of neglect significantly increased height, diameter, and crown spread of Rocky Mountain juniper, boxelder, green ash, American elm, Siberian elm, and Siberian peashrub growing in medium- to coarse-textured soils.

VAN HAVERBEKE, DAVID F.
1973.

Renovating old deciduous windbreaks with conifers.

J. Soil Water Conserv. 28:65-68.

Eastern redcedar, ponderosa pine, and Austrian pine seedlings were evaluated for renovating old windbreaks. Control of competing vegetation during establishment and distance from residual windbreak trees--both directly related to availability of soil moisture--were key factors in successful establishment of planted seedlings.

VAN HAVERBEKE, DAVID F.
1974.

Use evergreens to renovate a windbreak.

Nebr. Coll. Agric.-Lincoln, Farm, Ranch Home Q. 21(1):12-14.

Decadent windbreaks can be renovated by replacing deteriorating rows of hardwoods with young evergreens. Control

of competing vegetation and distance from remaining old windbreak trees -- both of which affect available soil moisture -- are key factors.

VAN HAVERBEKE, DAVID F., LEON CHESNIN,* AND DAVID R. MILLER.*
1976.

Feedlot waste runoff and mortality of windbreak trees.

J. Soil and Water Conserv. 31(1):14-17.

Runoff from confinement feedlots, flowing through windbreaks, killed mature trees. Feedlot runoff increased soil pH and conductivity and altered the exchangeable cation status but probably not enough to kill the trees. Heavy metals and organic substances leaching through the soil could also have been toxic.

Urban Forestry

COOK, DAVID I.,* AND DAVID F. VAN HAVERBEKE.
1972.

The potential value of trees, shrubs, and land form combinations for noise control.

Int. Shade Tree Conf., Midwest. Chapter [Chicago, Ill., Feb. 1972] 27:19-25.

Along highways, plant belts of trees and shrubs 65 to 100 feet wide, 50 to 80 feet from traffic. Take advantage of natural vegetation, ground forms, and tall grass or other soft ground cover.

COOK, DAVID I.,* AND DAVID F. VAN HAVERBEKE.
1972.

Trees and shrubs can curb noise, but with quite a few loud 'ifs'.

U. S. Dep. Agric. Yearb. 1972:28-30.

Knowledge of outdoor sound propagation, plus experience, is necessary in designing sound barriers with trees and shrubs.

COOK, DAVID I.,* AND DAVID F. VAN HAVERBEKE.
1972.

Trees, shrubs, and land-forms for noise control.

J. Soil Water Conserv. 27:259-261.

Tape-recorded and actual sounds of trucks, cars, and buses were used to determine the sound-attenuating properties of combinations of trees, shrubs, and land-forms. Recommendations for selection and optimum placement of tree structures are presented as well as tentative recommendations for forested land-form size and placement. (Paper presented at Soil Conservation Society of America's annual meeting, Portland, August 1972.)

COOK, DAVID I.,* AND DAVID F. VAN HAVERBEKE.
1972.

Trees, shrubs, and land-forms for noise control.

Soil Conserv. Soc. Am. [Portland, Ore., Aug. 1972] Proc. 27:151-154.

Tape-recorded and actual sounds of trucks, cars, and buses were used to determine the sound-attenuating properties of combinations of trees, shrubs, and land-forms. Recommendations for selection and optimum placement of tree structures are presented as well as tentative recommendations for forested land-form size and placement.

COOK, DAVID I.,* AND DAVID F. VAN HAVERBEKE.
1974.

Tree-covered land-forms for noise control.

Nebr. Agric. Exp. Stn. Res. Bull. 263, 47 p.

Combinations of trees, shrubs, and solid barriers effectively shield sensitive areas from noise. Sound reductions of 10 to 15 decibels (less than half as loud) are common for 12-ft high land-forms with wide belts of tall trees. Includes optimum heights for several applications, and instructions for establishing trees and shrubs on land-forms.

COOK, DAVID I.,* AND D. F. VAN HAVERBEKE.

1975.

Noise control.

p. 282-284, *In Yearbook of Science and Technology*, 1974. 460 p. McGraw-Hill, N.Y.

Wide belts of tall, dense trees can reduce traffic noise by 10 dB (cut noise in half). Combining trees and shrubs with solid landforms 10 feet high can reduce noise 15 dB. The barrier should be closer to the noise source than to the receiver.

SCHUBERT, GILBERT H.

1975.

Silviculturist's point of view on use of nonlocal trees.

USDA For. Serv. Gen. Tech. Rep. RM-11, 12 p.

Describes important factors that affect the health and vigor of forest trees introduced into communities and high density recreation areas. Seed origin, climatic and edaphic factors, and mycorrhizae are discussed first followed by insects, diseases, animal damage, and species selection.

VAN HAVERBEKE, DAVID F., AND DAVID I. COOK.*

1972.

Green mufflers.

Am. For. 78(11):28-31.

With quantitative data now available, significant noise abatement projects are currently being designed with trees, shrubs, and landforms. Dense masses of trees and shrubs are needed to reduce irritating noise to an acceptable level.

VAN HAVERBEKE, DAVID F., AND DAVID I. COOK.*

1974.

Studies in noise pollution reduction.

Am. Nurseryman 139(11):7,35-38; (12):11,71-75.

This two-part article describes how trees and shrubs reduce noise, and suggests plantings for reducing noise pollution. Suburban plantings can reduce noise levels 5 to 8 decibels, cutting loudness almost in half.

Survey, Inventory: See Assessment (Resource Inventories, Techniques) under RESOURCE ASSESSMENT AND ECONOMICS

Transportation Systems

WONG, PETER,* JORGE BARRIGA,* AND D. ROSS CARDER.

1975.

Methods for estimating traffic volumes and composition on National Forest roads.

p. 257-266. *In Low-volume roads*. NRC Transp. Res. Board Spec. Rep. 160, 396 p. Natl. Acad. Sci., Wash., D.C.

Concepts of traffic volume sampling and analysis are discussed in terms of probability theory and statistical inference. Modeling techniques were developed to estimate travel generated by recreation, logging, and administration under alternative management strategies.

Damage (Wildlife, Physical) and Protection

GOTTFRIED, GERALD J., AND JOHN R. JONES.

1975.

Logging damage to advance regeneration on an Arizona mixed conifer watershed.

USDA For. Serv. Res. Pap. RM-147, 20 p.

Damage to advance regeneration was studied after harvesting where special care was taken to avoid damage. With the selection method, 50 percent was destroyed, and in a one-cut overstory removal, 65 percent. The overstory removal area was left seriously understocked. Logging modifications are recommended to further reduce damage.

HEIDMANN, L. J.

1972.

An initial assessment of mammal damage in the forests of the Southwest.

USDA For. Serv. Res. Note RM-219, 7 p.

All size classes of trees are affected, but the problem is most serious in plantations and young trees. Mammals are a major factor in preventing the establishment of regeneration on one-half million acres of nonstocked forest land in the Southwest.

HEIDMANN, LEROY J.

1973.

Frost heaving in ponderosa pine.

West. For. Conserv. Assoc., Perm. Assoc. Comm. [San Jose, Calif., Dec. 1973] Proc. 1973:136-138.

Frost heaving results when soil water moves upward to a freezing zone where layers of pure ice are formed, lifting the soil. Several chemicals apparently reduce frost heaving without damaging seedlings. Plowing may also help by reducing soil bulk density, a directly related factor.

HEIDMANN, L. J., AND DAVID B. THORUD.*

1975.

Effect of bulk density on frost heaving of six soils in Arizona.

USDA For. Serv. Res. Note RM-293, 4 p.

For all soils and depths, frost heaving increased with bulk density. All soils had essentially the same water content when they started to freeze. At higher bulk densities, capillary flow is probably improved.

HEIDMANN, L. J.

1975.

Predicting frost heaving susceptibility of Arizona soils.

USDA For. Serv. Res. Note RM-295, 7 p.

This study used 15 variables in a stepwise regression analysis to develop an equation for predicting frost heaving susceptibility. Bulk density, sand content, and calcium accounted for 83 percent of the total variation in heaving.

HEIDMANN, L. J.

1976.

Frost heaving of tree seedlings: A literature review of causes and possible control.

USDA For. Serv. Gen. Tech. Rep. RM-21, 10 p.

Frost heaving is most serious among seedlings less than 1 year old. It appears to be a surface soil phenomenon. Soil water segregates and freezes into lenses of ice. Lens formation lifts the surface soil and the seedling. Upon thawing, the tree remains extruded on the soil surface.

NOBLE, DANIEL L., AND WAYNE D. SHEPPERD.

1973.

Grey-headed [Gray-headed] juncos important in first season mortality of Engelmann spruce.

J. For. 71:763-765.

Juncos clip attached seedcoats from newly germinated seedlings. In a 5-year study, these birds clipped 20 percent of the seedlings and were the second leading cause of first-season mortality in clearcut openings.

Experimental Techniques, Equipment

BARNHART, MICHAEL R.

1976.

A new compact pollinator.

USDA For. Serv. Res. Note RM-310, 2 p.

This simple, inexpensive pollinator is compact, waterproof, nonclogging, and requires only small quantities of pollen. It was used successfully for pollinating Scotch pine in a breeding program.

HEIDMANN, L. J.

1974.

An inexpensive chest for conducting frost-heaving experiments.

USDA For. Serv. Res. Note RM-269, 4 p.

A freezing chest constructed of plywood and styrofoam is described which can be built for approximately \$60 (1974 costs).

NOBLE, DANIEL L., AND ROBERT R. ALEXANDER.

1975.

Rodent enclosures for the subalpine zone in the central Colorado Rockies.

USDA For. Serv. Res. Note RM-280, 4 p.

Two enclosures have effectively excluded rodents from an Engelmann spruce regeneration study. They have withstood deep snowpacks and required little maintenance during 6 years. Method of construction and recommendations for use are discussed.

RIETVELD, W. J.

1975.

An inexpensive truck-mounted ladder for inspecting conelet development and collecting cones.

USDA For. Serv. Res. Note RM-288, 4 p.

The versatile rig is stable, durable, quickly moved from tree to tree, and easily removed from the truck.

SHEPPERD, WAYNE D.

1973.

An instrument for measuring tree crown width.

USDA For. Serv. Res. Note RM-229, 3 p.

A small, handheld instrument for measuring tree crown widths has proved to be accurate, and has several advantages over existing equipment.

TRUJILLO, DAVID P.

1975.

Preparing aspen increment cores for ring counts.

J. For. 73(7):428.

To make counting of aspen rings easier, shave one side of fresh cores, oven-dry, moisten shaved surface with penta in kerosene or mineral spirits, then oven-dry again.

Multiple Use Relations

ALDON, EARL F., AND H. W. SPRINGFIELD.

1973.

The southwestern pinyon-juniper ecosystem: A bibliography.

USDA For. Serv. Gen. Tech. Rep. RM-4, 20 p.

Publications are categorized under six major headings: ecological investigations, silvics and management aspects, product utilization, range characteristics and wildlife values, water yield and sediment, and insects and diseases.

BERNTSEN, CARL M.

1975.

Management conflicts in lodgepole pine.

p. 503-515. In Manage. Lodgepole Pine Ecosyst. Symp. [Pullman, Wash., Oct. 1973] Proc., 2 vols. David M.

Baumgartner, ed. Wash. State Univ., Pullman.

Clearcutting since 1950 has generated widespread concern as to possible adverse effects on the other forest land resources. This paper discusses management alternatives to resolve conflicts related to harvesting methods, scenic quality, wildlife, recreation, reforestation, and logging residues.

CLARY, WARREN P.

1975.

Present and future multiple use demands on the pinyon-juniper type.

p. 19-26. In The pinyon-juniper ecosystem: A symposium, May 1975. Utah State Univ., Utah Agric. Exp. Stn., Logan, Utah. 194 p.

Because of increasing pressures for livestock grazing, wildlife, and wood products, optimum management should result in a shifting mosaic of activities, with each site managed for the product or product mix for which it is best suited.

FFOLLIOTT, PETER F.,* AND WARREN P. CLARY.

1974.

Predicting herbage production from forest growth in Arizona ponderosa pine.

Prog. Agric. Ariz. 26(3):3-5.

Annual herbage production decreased as annual forest growth increased, in an unexpected linear relationship. Herbage prediction was improved by developing families of curves that added precipitation and elevation strata to timber growth.

FFOLLIOTT, PETER F.,* AND WARREN P. CLARY.

1975.

Differences in herbage-timber relationships on sedimentary and igneous soils in Arizona ponderosa pine stands.

Prog. Agric. Ariz. 27(3):6-7.

Significant differences in herbage-timber relationships on sedimentary and igneous soils indicate that herbage production predictions that do not account for soil differences may not be sufficiently accurate for use in land use planning or stratification.

FFOLLIOTT, PETER F.,* WARREN P. CLARY, AND MALCHUS B. BAKER, JR.

1976.

Characteristics of the forest floor on sandstone and alluvial soils in Arizona's ponderosa pine type.

USDA For. Serv. Res. Note RM-308, 4 p.

The forest floor affects the hydrologic cycle, herbage production, tree regeneration, and fire behavior. Forest floor depths and weights under ponderosa pine stands on soils developed from sedimentary parent materials were similar to those previously found on soils developed from volcanics.

MYERS, CLIFFORD A.

1974.

Multipurpose silviculture in ponderosa pine stands of the Montane Zone of central Colorado.

USDA For. Serv. Res. Pap. RM-132, 15 p.

Presents silvicultural prescriptions for ponderosa pine in an area where several uses and products of the forest are important, but scenic and recreation values predominate.

SEVERSON, KIETH E., AND CHARLES E. BOLDT.

1976.

Quality and quantity of forage and wood as related to tree stocking levels in Black Hills ponderosa pine.

Soc. Range Manage. [Omaha, Nebr., Feb. 1976] Abstr. of Pap. 29:37.

Diameter growth of trees was most rapid at lower stocking levels. Stocking level did not affect wood quality, however, or forage quality of a shrub and a grass, but a forb had higher digestible dry matter under unthinned saplings.

FOREST PRODUCTS

*Private, State or Federal cooperator

Harvesting (Product-Related)

SAMPSON, GEORGE R., HAROLD E. WORTH, AND DENNIS M. DONNELLY.

1974.

Demonstration test of inwoods pulp chip production in the Four Corners region.

USDA For. Serv. Res. Pap. RM-125, 19 p.

Pulpwood and noncommercial material were chipped by a portable debarker-chipper in two test areas: a ponderosa pine site in Arizona, and a spruce-fir site in Colorado. Chips from both areas were delivered to a pulpmill at Snowflake, Arizona. Feasibility analysis included physical, economic, and environmental evaluation.

Wood Structure, Species Characteristics

BARGER, ROLAND L., AND PETER F. FFOLIOTT.

1972.

Physical characteristics and utilization of major woodland tree species in Arizona.

USDA For. Serv. Res. Pap. RM-83, 80 p.

Woodland species in the Southwest, primarily Utah and alligator juniper, pinyon pine, and Gambel oak, represent a vast resource potentially useful for veneer, particleboards, charcoal, pulp, and chemical extractives.

BARGER, ROLAND L., AND PETER F. FFOLIOTT.

1976.

Factors affecting occurrence of compression wood in individual ponderosa pine trees.

Wood Sci. 8(3):201-208.

Lean, either by itself or in combination with other visual tree characteristics, was an unreliable predictor of compression wood in northern Arizona. Release through thinning or partial cutting may substantially increase incidence of compression wood in trees that respond with increased growth rates.

BOLDT, C. E., AND C. (D.) MARKSTROM.

1972.

Rapid growth and wood quality in Black Hills ponderosa pine.

For. Prod. Res. Soc. [Dallas, Tex., June 1972] Abstr. 26:6.

Thinning to hasten growth increased ring width, but specific gravity, percent late wood, and percent extractives were not significantly changed.

MARKSTROM, DONALD C., AND ROBERT A. HANN.*

1972.

Seasonal variation in wood permeability and stem moisture content of three Rocky Mountain softwoods.

USDA For. Serv. Res. Note RM-212, 7 p.

Time of year does not affect wood permeability but does affect water content of Engelmann spruce, lodgepole pine, and Douglas-fir trees, especially the sapwood. The water contents were highest during winter.

MARKSTROM, DONALD C., AND VERN P. YERKES.

1972.

Specific gravity variation with height in Black Hills ponderosa pine.

USDA For. Serv. Res. Note RM-213, 4 p.

Average specific gravity decreased with increasing height up the merchantable stem. The mature trees with d.b.h. 11.0 inches or less had the highest specific gravity at all stem levels. The table presented provides a means of predicting specific gravity at different relative heights of the merchantable stem.

Timber Manufacturing

ERIKSON, BERNARD J., AND DONALD C. MARKSTROM.

1972.

Predicting softwood cutting yield by computer.

USDA For. Serv. Res. Pap. RM-98, 15 p.

A computer program, written in FORTRAN, predicts the maximum yield of cutting for a softwood cut-up and edge- and end-gluing operation. The program calculates cutting recovery (given cutting width and length constraints and defect locations on the board), and locates ripping saw kerfs.

YERKES, VERN P., AND R. O. WOODFIN, JR.*

1972.

Veneer recovery from Black Hills ponderosa pine.

USDA For. Serv. Res. Pap. RM-82, 23 p.

Veneer recovered from a selected sample of 144 sawtimber trees was sufficient in both volume and grades to allow production of at least 3/8-inch C-D plywood.

YERKES, VERN P.

1974.

Black Hills ponderosa pine timber: Poles, saw logs, veneer logs, stud logs, or pulp.

USDA For. Serv. Res. Pap. RM-118, 12 p.

A multiproduct analysis indicates gross volumes per acre of 4,944 fbm of saw logs, 4,680 fbm of veneer logs, or 3,052 fbm of stud logs if inventoried for these products individually. If inventoried simultaneously for highest multiproduct potentials, however, gross allocated volumes were 881, 3,165, and 143 fbm per acre.

Wood Protection

MARKSTROM, DONALD C., AND DAVID H. CLARK.

1975.

Service life of treated and untreated Black Hills ponderosa pine fenceposts: A progress report.

USDA For. Serv. Res. Note RM-303, 4 p.

Ponderosa pine fenceposts treated with preservatives are performing favorably after field exposures of 13 to 14 years. Test sites are in the Northern Great Plains--one in the semiarid western portion near Scenic, South Dakota; the other in the more humid eastern portion near Brookings.

Adhesives and Bonded Products

MUELLER, LINCOLN A., ROLAND L. BARGER, ARTHUR BOURKE,* AND DONALD C. MARKSTROM.

1972.

Roll laminating fiber overlays on low-grade ponderosa pine lumber.

USDA For. Serv. Res. Pap. RM-97, 28 p.

In pilot plant tests, lumber was satisfactorily overlaid at speeds up to 180 fpm. at a cost, exclusive of substrate, of 4 to 5 cents per square foot. Commercial feasibility is restricted by need for an effective automated defect repair system, and lack of assured markets.

Market Analyses, Development, Statistics

LEWIS, GORDON D.

1973.

The wood pole market: recent trends and outlook. In The changing polescape.

Wood Pole Inst. [Fort Collins, Colo., July 1971] Proc. 5:10-19.

The number of wood poles treated each year has been declining since 1966. The increasing trend toward underground utility systems is likely a major factor. Esthetic and other advantages of pole-frame construction could greatly enlarge alternative markets, however.

WORTH, HAROLD E.

1973.

Prospects for new particleboard production in the Rocky Mountains.

p. 58-72. In 'MULE'--Multi-product utilization, labor, and equipment. Rocky Mt. For. Ind. Conf. [Rapid City, S.D., Apr. 1973] Proc. 72 p.

Prospects are favorable due to increasing national demand, plentiful raw materials, and favorable locations with respect to major markets. New producers should make a careful choice between product alternatives and production systems, since the \$6 to \$10 million capital investment required makes it difficult to shift products.

Residue Use

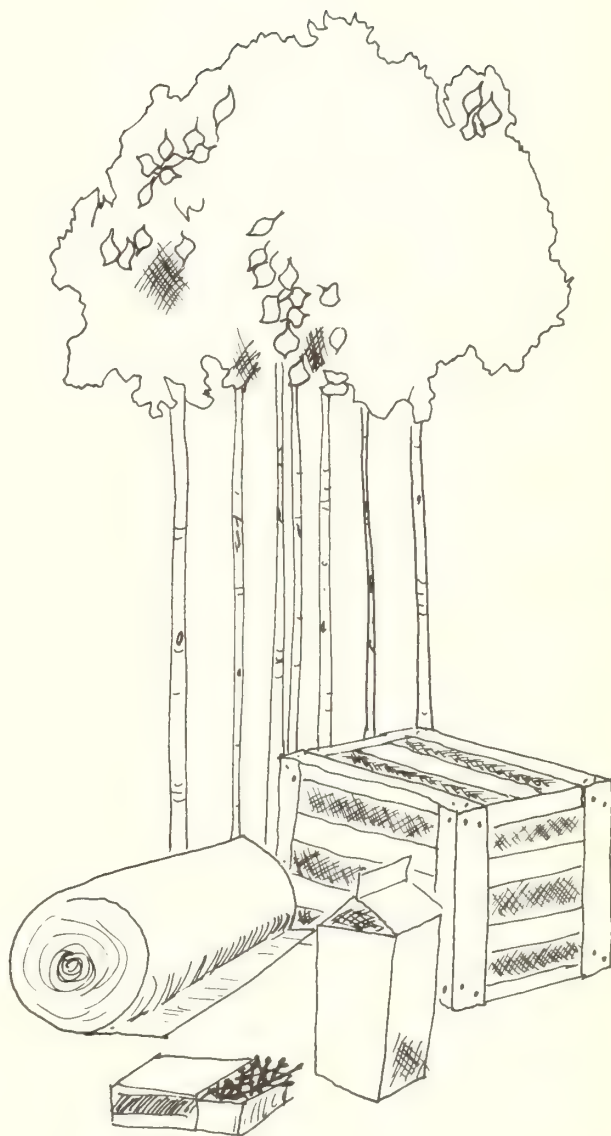
SABEY, B. R.,* N. N. AGBIM,* AND D. C. MARKSTROM.

1975.

Land application of sewage sludge: III. Nitrate accumulation and wheat growth resulting from addition of sewage sludge and wood wastes to soils.

J. Environ. Qual. 4(3):388-393.

Mixtures of anaerobically digested sewage sludge and wood-bark residues increased wheat growth in greenhouse studies. Wood and bark partially immobilized nitrate ions, and slowed leaching. Wheat growth was optimum when wood-bark residue was not more than 25 percent of the mixture with sludge.



RANGE AND WILDLIFE HABITAT MANAGEMENT

*Private, State or Federal cooperator

Plant Taxonomy

CRUM, HOWARD,* AND F. J. HERMANN.

1972.

Sphagnum magellanicum new to the West Indies.

Bryologist 75:359-360.

Sphagnum magellanicum is recorded from Jamaica and the Dominican Republic as first records for the West Indies.

FEDDEMA, CHARLES.

1972.

Sclerocarpus uniserialis (Compositae) in Texas and Mexico.

Phytologia 23:201-209.

The species has three varieties. Variety *uniserialis* occurs in Texas, a newly described var. *rubridiscus* occurs in southwest Mexico, and var. *frutescens* ranges from eastern Mexico to Guatemala. Hybrids of the last two occur in southern Mexico.

HERMANN, FREDERICK J.

1972.

A new variety of *Carex bicknellii* from Arkansas.

Sida 5(1):49.

Describes and discusses a new variety that has long been confused with *Carex brittoniana*.

HERMANN, FREDERICK J.

1973.

Additions to the bryophyte flora of Alaska.

Bryologist 76:442-446.

Nine hepatic and 32 moss taxa are added to the known flora of Alaska. Three dubious earlier reports are verified, and new stations included for two rare species.

HERMANN, FREDERICK J.

1973.

Additions to the bryophyte flora of Mt. McKinley National Park, Alaska.

Bryologist 76:563-565.

Six hepatic and 27 moss taxa are added to the known flora.

HERMANN, FREDERICK J.

1974.

Manual of the genus *Carex* in Mexico and Central America.

U.S. Dep. Agric., Agric. Handb. 467, 219 p.

An original treatment of the 102 taxa of the genus *Carex* (family Cyperaceae) now known from Mexico and Central America. Detailed descriptions, keys for identification, and illustrations for each species are included. (Available from Superintendent of Documents, Stock No. GPO 0100-03259, \$2.85, paper cover.)

HERMANN, FREDERICK J., AND HAROLD ROBINSON.*

1974.

Additions to the bryophyte flora of Bolivia.

Bryologist 66(4):643-645.

Based upon the senior author's 1972 collections, 12 hepatics and 14 mosses are added to the known flora of Bolivia.

HERMANN, FREDERICK H.

1975.

Manual of the rushes (*Juncus* spp.) of the Rocky Mountains and Colorado Basin.

USDA For. Serv. Gen. Tech. Rep. RM-18, 107 p.

A taxonomic treatment of the 51 taxa of the critical genus *Juncus* known from the Rocky Mountains and Colorado Basin. Detailed descriptions, synonymy, key for identification, illustrations, habitats, geographic distribution, and data on forage value are included.

LAWTON, ELVA,* AND F. J. HERMANN.

1973.

A new *Orthotrichum* from northern California.

Bryologist 76:437-439.

Orthotrichum epapillosum Lawt. and Herm. is described as a new species from California. It differs from other species with immersed stomata, in its epapillose leaf cells. The calyptra is without hairs and the apices of mature leaves are broad and rounded.

NICKERSON, MONA F., GLEN E. BRINK, AND CHARLES FEDDEMA.

1976.

Principal range plants of the central and southern Rocky Mountains: Names and symbols.

USDA For. Serv. Gen. Tech. Rep. RM-20, 121 p.

Provides scientific names, useful synonyms, common names (where available), and standard symbols for use in field records. Scientific names are generally those from manuals specified as authoritative by Forest Service policy. The list has been prepared by use of data processing equipment.

Plant Physiology, Morphology, Genetics

ALCORN, STANLEY M.,* AND S. CLARK MARTIN.

1974.

Cereus giganteus Engelm. Saguaro.

p. 313-314. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

ALEXANDER, ROBERT R., KENT JORGENSEN,* AND A. P. PLUMMER.*

1974.

Cowania mexicana var. *stansburiana* (Torr.) Jepsen. Cliffrose.

p. 353-355. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

ALEXANDER, ROBERT R., AND FLOYD W. POND.

1974.

Yucca (L.). Yucca.

p. 857-858. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

CABLE, DWIGHT R.

1974.

- Early development of range grass inflorescence.**
Prog. Agric. Ariz. 26(1):8-9.
 The seed-producing process begins with microscopic changes in the growing point at the upper end of the shoot. A single bite by a hungry cow at this stage can not only destroy the developing seed head, but also a foot or more of developing shoot and leaves.
- CLARY, WARREN P.**
1975.
Ecotypic adaptation in *Sitanion hystrix*.
Ecology 56(6):1407-1415.
 The populations studied adapted to different climatic conditions primarily through variations in timing of phenological development and in rate of growth. No differences in water use efficiency were found. The primary factors which influence morphological and production characteristics may be more numerous or complex than those which influence phenology.
- DIETZ, DONALD R., AND PAUL E. SLABAUGH.**
1974.
***Caragana arborescens* Lam. Siberian peashrub.**
p. 262-264. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- EVANS, KEITH E.**
1974.
***Symphoricarpos* Duham. Snowberry.**
p. 787-790. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- KNIPE, O. D., AND H. W. SPRINGFIELD.**
1972.
Germinable alkali sacaton seed content of soils in the Rio Puerco Basin, west central New Mexico.
Ecology 53:965-968.
 Most seeds are blown across barren sites interspersed through native stands. The few seeds trapped in microsites in the soil apparently are either removed by wind, water, animals, or insects, or are killed due to unfavorable moisture-temperature conditions.
- KNIPE, O. D.**
1973.
Western wheatgrass germination as related to temperature, light, and moisture stress.
J. Range Manage. 26:68-69.
 Germination of western wheatgrass was best when seeds were held for 16 hours at temperatures between 55 F. and 75 F. and 8 hours at temperatures between 75 F. and 90 F. daily. Germination was independent of light, but was severely reduced by moisture stresses above 1.0 atmospheres.
- KNIPE, O. D.**
1974.
Effect of heat treatment on germination of alkali sacaton.
USDA For. Serv. Res. Note RM-268, 3 p.
 Dry seeds withstood 225 degrees F without injury. Large seeds which had imbibed for 8 hours and small seeds which had imbibed for 4 hours were injured by heating at 160 degrees F for 1 hour. Both large and small seeds were injured by 150 degrees F after 24 hours' imbibition.
- MARTIN, S. CLARK.**
1974.
***Larrea tridentata* Vail. Creosotebush.**
p. 486-487. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- MARTIN, S. CLARK, AND ROBERT R. ALEXANDER.**
1974.
***Prosopis juliflora* (Swartz) DC. Mesquite.**
p. 656-657. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- REYNOLDS, HUDSON G., AND ROBERT R. ALEXANDER.**
1974.
***Garrya Dougl.* Silktassel.**
p. 420-421. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- REYNOLDS, H. G., AND ROBERT R. ALEXANDER.**
1974.
***Tamarix pentandra* Pall. Five-stamen tamarisk.**
p. 794-795. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- SEVERSON, KEITH E., AND E. CHESTER GARRETT.**
1974.
Growth characteristics of bearberry in the Black Hills.
USDA For. Serv. Res. Note 254, 3 p.
 Growth of bearberry (*Arctostaphylos uva-ursi*) varied widely between plants and between sites. Most annual growth (66 percent) occurred during June when moisture and temperature conditions were apparently optimum. Annual growth can readily be recognized by the presence of nodes and by color changes.
- SLABAUGH, PAUL E.**
1974.
***Cotoneaster* B. Ehrh. Cotoneaster.**
p. 349-352. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- SLABAUGH, PAUL E.**
1974.
***Hippophae rhamnoides* [rhamnoides] L. Common seabuckthorn.**
p. 446-447. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.
 Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.
- SMITH, DWIGHT R., AND LOUIS N. BASS.***
1973.
Germinability of true mountainmahogany achenes as influenced by soil and other environmental factors.
Proc. Assoc. Off. Seed Anal. 63:126-134.
 Differences in percent germination, percent filled, and weights of true mountainmahogany achenes on four mountain soils were highly significant. Germination, fill, and weight were greater from northwest aspects than from southwest. Achenes with highest germination were from plants on northwest aspects in the least fertile soil, which had the lowest population of mountainmahogany.
- SPRINGFIELD, H. W.**
1972.
Optimum temperatures for germination of winterfat.
J. Range Manage. 25:69-70.
 Optimum temperatures for germination were 50 to 80 F. Germination was practically complete within 5 days at 59 F.

SPRINGFIELD, H. W.

1972.

Winterfat seeds undergo after-ripening.

J. Range Manage. 25:479-480.

Seeds were collected in 4 consecutive years in New Mexico. After-ripening was completed within 10 weeks for all except one collection, which required 25 weeks.

SPRINGFIELD, H. W.

1973.

Winterfat fruits and seeds retain high viability 3 years in cold storage.

USDA For. Serv. Res. Note RM-233, 3 p.

Fruits and seeds of winterfat (*Eurotia lanata*) were stored 3 years in sealed and unsealed containers under four temperatures. Seed stored in sealed containers under refrigeration or subzero temperatures retained 93 to 99 percent viability. By contrast, seed stored in unsealed containers under room conditions retained only 46 percent viability, and under outside shed conditions, only 3 percent viability. Cold storage in sealed containers is recommended.

SPRINGFIELD, H. W.

1973.

Cliffrose and mountainmahogany seeds retain viability 6 years in cold storage.

USDA For. Serv. Res. Note RM-236, 2 p.

Viability was highest for seeds stored at -5 to -10 F. or 36 to 44 F.

SPRINGFIELD, H. W.

1973.

Larger seeds of winterfat germinate better.

J. Range Manage. 26:153-154.

Seeds of winterfat (*Eurotia lanata*) were separated into three size classes and germinated under four temperature regimes. Large- and medium-size seeds germinated better and faster.

SPRINGFIELD, H. W.

1974.

Winterfat seeds viable after 8 years refrigerated storage.

J. Range Manage. 27:78.

Five collections of winterfat seeds from New Mexico were stored in cans under refrigeration and ordinary temperatures. After 8 years, viability ranged from 51 to 80 percent for the refrigerated seeds, but practically no seeds remained viable under the warmer storage temperatures.

SPRINGFIELD, H. W.

1974.

***Eurotia lanata* (Pursh) Moq. Winterfat.**

p. 398-400. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

THILENIUS, JOHN F., KEITH E. EVANS, AND E. CHESTER GARRETT.

1974.

***Shepherdia* Nutt. Buffaloberry.**

p. 771-773. In Seeds of woody plants in the United States. U.S. Dep. Agric., Agric. Handb. 450, 883 p.

Briefly describes general growth, flowering, and fruiting characteristics of the species and summarizes available information on seed handling, testing, and nursery practices.

WILLIAMS, S. E.,* A. G. WOLLUM II,* AND EARL F. ALDON.

1974.

Growth of *Atriplex canescens* (Pursh) Nutt. improved by formation of vesicular-arbuscular mycorrhizae.

Soil Sci. Soc. Am. Proc. 38:962-965.

Mycorrhizal fourwing saltbush grown in nonsterile soil were heavier and accumulated more phosphorus than nonmycorrhizal

plants grown in sterile soil. Inoculation of fourwing saltbush with a known endomycorrhizal fungus, *Endogone mosseae* stimulated plant growth.

WILLIAMS, STEPHEN E., AND EARL F. ALDON.

1976.

Endomycorrhizal (vesicular arbuscular) associations of some arid zone shrubs.

Southwest. Nat. 20(4):437-444.

Vesicular arbuscular endomycorrhizae were observed in association with several shrubs important for livestock and wildlife. Root fungi were stained using acid fuchsin in chloral hydrate solution. Fungal spores were extracted from soil by centrifugal flotation or sieving-decanting methods.

Herbage Growth, Values

CABLE, DWIGHT R., AND S. CLARK MARTIN.

1975.

Vegetation responses to grazing, rainfall, site condition, and mesquite control on semidesert range.

USDA For. Serv. Res. Pap. RM-149, 24 p.

Over a 10-yr period, mesquite control increased perennial grass production 52 percent. Perennial grass production was highly dependent on both the previous and current summer's rainfall, indicating 2 yrs are required for recovery from a 1-yr drought. Stocking rates could be estimated as accurately from rainfall as from grass production.

CABLE, DWIGHT R.

1975.

Influence of precipitation on perennial grass production in the semidesert Southwest.

Ecology 56(4):981-986.

Production depended primarily on current summer and previous summer rainfall. Previous summer rainfall was an interaction effect. The best overall relationship involved current August rainfall, previous June-through-September rainfall, and their interaction product. Winter precipitation had no consistent effect on perennial grass production the following summer.

CLARY, WARREN P., AND DOUGLAS C. MORRISON.*

1973.

Large alligator junipers benefit early-spring forage.

J. Range Manage. 26:70-71.

Production of early-spring grasses in central Arizona was 4 to 5 times higher under crowns of large alligator junipers than away from trees. Because virtually all green forage grazed by animals at this time of year grew under these trees, they should be protected during control operations.

CLARY, WARREN P.

1974.

Response of herbaceous vegetation to felling of alligator juniper.

J. Range Manage. 27:387-389.

Felling a 13 percent cover of alligator juniper in northcentral Arizona increased total herbage production 38 percent and forage plant production 45 percent. These increases were highly variable. There was little or no apparent response in 3 of 7 postfelling years.

CLARY, WARREN P., AND HENRY A. PEARSON.*

1976.

Herbage changes following thinning and grazing of a southwestern ponderosa pine stand.

Soc. Range Manage. [Omaha, Nebr., Feb. 1976] Abstr. of Pap. 29:37.

After pine stands are thinned, herbage yields usually increase rapidly to levels considerably higher than under unthinned stands of similar basal area, then slowly decline. Grazing accelerates

the decline. Plant composition (seeded versus native) is not necessarily an important factor.

MARTIN, S. CLARK.

1972.

Some effects of continuous grazing on forage production.

Ariz. Cattlelog 28(10):17-18, 23-25.

Many semidesert ranges need systems of grazing that will give perennial grasses a chance to recover on closely grazed areas. On the Santa Rita Experimental Range, resting the range March to October 2 years out of 3 has been more effective than closing waters during the summer growing season.

THILENIUS, JOHN F.

1975.

Plant production of three high-elevation ecosystems. p. 60-75. In The Medicine Bow ecology project, final report, February 28, 1975. D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.

Provides quantitative information on above- and belowground biomass (live vegetation, standing dead vegetation, litter, and root biomass) of two alpine tundra and one subalpine meadow ecosystem in the Medicine Bow Mountains. Data are presented by biweekly intervals for two growing seasons. (Entire report available from NTIS, 397 p., \$3.)

THILENIUS, JOHN F., AND GARY R. BROWN.

1976.

Effect of 2,4-D on digestibility and production of subalpine herbage.

J. Range Manage. 29(1):63-65.

Treating forb-dominated subalpine cattle range in the Bighorn Mountains, Wyoming, did not change digestibility coefficients of grasses or surviving forbs. Forbs and grasses were equally digestible throughout the growing season. Production of total and digestible dry matter was not increased.

Measurement Methods and Equipment: See also Assessment (Resource Inventories, Techniques) under RESOURCE ASSESSMENT AND ECONOMICS

CARPENTER, L. H.,* O. C. WALLMO, AND M. J. MORRIS.

1973.

Effect of woody stems on estimating herbage weights with a capacitance meter.

J. Range Manage. 26:151-152.

Herbage weight can be estimated more accurately by ignoring the contribution of woody stems to capacitance readings. These stems should be clipped and measured only if an estimate of total biomass is desired.

CURRIE, PAT O., M. J. MORRIS, AND D. L. NEAL.*

1973.

Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 2. Sown ranges.

J. Brit. Grassl. Soc. 28:155-160.

A meter effectively estimated herbage yields of sown ranges in Arizona and Colorado. Methods of placing the meter in relation to drill rows, cutting procedures, and evaluation of organic matter are described which avoid biased estimates and improve regressions. Part 1 describes evolution of the meter.

FRANCIS, RICHARD E., RICHARD S. DRISCOLL, AND JACK N. REPPERT.

1972.

Loop-frequency as related to plant cover, herbage production, and plant density.

USDA For. Serv. Res. Pap. RM-94, 8 p.

Frequency measured by the 3/4-inch loop technique was compared to estimates of plant basal cover, foliar cover, herbage production, and density. The relationship between loop-frequency and the other parameters were rarely significant or consistent as determined by regression and correlation. Loop-frequency unpredictably overrated foliar and basal plant cover on the basis of ratio estimates, a relative measure of bias. Therefore, frequency estimated by the 3/4-inch loop technique can be equated only to itself and not used to make inferences about other plant community parameters.

MORRIS, MEREDITH J.

1973.

Estimating understory plant cover with rated microplots.

USDA Forest Serv. Res. Pap. RM-104, 12 p.

Trained range personnel rate small plots similarly in respect to area occupied by aerial and basal plant cover. Equal area rectangles and circles ranging from 1/8 square inch to 8 square inches were used. All are well suited for rating plant cover, although smaller sizes were slightly more precise.

MORRIS, MEREDITH J., KENDALL L. JOHNSON, AND DONALD L. NEAL.*

1976.

Sampling shrub ranges with an electronic capacitance instrument.

J. Range Manage. 29(1):78-81.

Electronic capacitance meters can provide a rapid, accurate, and nondestructive means of estimating total aboveground and herbaceous dry matter yields in low-shrub lands. A double sampling technique is necessary to obtain reliable yield estimates, maximum cost reduction, and the most efficient use of the meters.

NEAL, D. L.,* AND J. L. NEAL.*

1973.

Uses and capabilities of electronic capacitance instruments for estimating standing herbage. Part 1. History and development.

J. Brit. Grassl. Soc. 28:81-89.

Problems with short or dry vegetation, nonhomogeneous distribution of vegetation, nonhomogeneous phenology, and electronic circuit instability have been greatly reduced by improvements in instrumentation. Instruments have proved their value under a wide variety of range conditions.

NEAL, DONALD L.,* PAT O. CURRIE, AND MEREDITH J. MORRIS.

1976.

Sampling herbaceous native vegetation with an electronic capacitance instrument.

J. Range Manage. 29(1):74-77.

Yields were estimated on vegetation types varying from a low-elevation annual type to a high-elevation alpine type. Phenology, dead organic matter, plant stature, composition, and meter placement within the vegetation affected efficiency of yield estimates. Double sampling techniques are necessary.

PATTON, DAVID R.

1974.

Estimating food consumption from twigs clipped by the Abert squirrel.

USDA For. Serv. Res. Note RM-272, 3 p.

Abert squirrels consume the inner bark of ponderosa pine twigs. Mean length, diameter, and dry weight of peeled twigs was 88 mm, 5.9 mm, and 1.3 g, respectively. A table gives dry weight of inner bark from dry weight of a peeled twig.

PATTON, DAVID R.

1975.

A diversity index for quantifying habitat 'edge.'

Wildl. Soc. Bull. 3(4):171-173.

The Diversity Index measures total perimeter plus any linear edge within an area, compared to the perimeter of a circle. Number of vegetation types and size of area make the index more meaningful. A DI of 1.69(4)1,000 would indicate a 1.69 index with four types on 1,000 acres.

REPPERT, JACK N., AND RICHARD E. FRANCIS.

1973.

Interpretation of trend in range condition from 3-step data.

USDA For. Serv. Res. Pap. RM-103, 15 p.

A 5-phase procedure uses 3-step data to identify trends and assign cause: (1) strict fieldwork, (2) determining tentative trend, (3) office tests and photointerpretation, (4) relating change characteristics to trends judged in the field, and (5) assigning probable trend causes.

SPRINGFIELD, H. W.

1974.

Using a grid to estimate production and utilization of shrubs.

J. Range Manage. 27:76-78.

Production of fourwing saltbushes was estimated from photographs against a 1-inch grid. All squares partially or completely obscured were counted. Utilization of several shrub species was estimated from photos taken before and after browsing by deer.

Livestock Management, Grazing Systems, Nutrition

CABLE, DWIGHT R.

1975.

Range management in the chaparral type and its ecological basis: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-155, 30 p.

Chaparral in Arizona is used far below its potential. Conversions to grass can greatly increase water and grass production, and improve wildlife habitat. Management options include conversion to grass, maintaining shrubs in a sprout stage, changing shrub composition, reseeding, and using goats to harvest shrub forage.

CLARY, WARREN P.

1975.

Range management and its ecological basis in the ponderosa pine type of Arizona: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-158, 35 p.

Summarizes and evaluates available information about Arizona ponderosa pine-bunchgrass ranges. It covers physical-biological characteristics, factors influencing livestock production, grazing allotment conditions, and economics, and correlates grazing with other uses. Several knowledge gaps are also identified.

CURRIE, PAT O.

1975.

Plant response and livestock weight changes on big bluegrass range grazed during late fall, winter, and early spring.

J. Range Manage. 28(5):340-343.

Yearling heifers gained weight during late fall with or without protein supplement, but less than animals that grazed native range and received protein. During winter and early spring,

animals lost weight. Grazing was not detrimental to Sherman big bluegrass during any period from late fall to early spring.

CURRIE, PAT O.

1975.

Grazing management of ponderosa pine-bunchgrass ranges of the central Rocky Mountains: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-159, 24 p.

Pine-bunchgrass ranges are important livestock-producing areas in the central Rocky Mountains. Livestock-management techniques are well developed and soundly based on research within the type. There is a need, however, to understand the interrelationships of other land uses, particularly as they relate to human population pressures.

GALT, H. D.,* BRENT THEURER,* AND S. CLARK MARTIN.

1972.

Botanical composition of cattle diets on velvet mesquite-fair and nonmesquite-good desert grassland.

Soc. Range Manage. [Wash., D.C., Feb. 1972] Abstr. of Pap. 25:12.

Animal diets were only slightly different between the two pastures; Arizona cottontop predominated in both. Protein content of fistula samples was consistently higher than that of the major available grasses. Excess protein was attributed to higher protein shrubs and parts of grasses.

MARTIN, S. CLARK, AND DONALD E. WARD.

1973.

Salt and meal-salt help distribute cattle use on semidesert range.

J. Range Manage. 26:94-97.

Placing salt or meal-salt 1 to 2-1/2 miles from water increased utilization of perennial grasses where use was usually light, but did not decrease use near water in the heavy use zone. No cattle injury due to either inadequate or excessive salt intake was observed.

MARTIN, S. CLARK.

1973.

Responses of semidesert grasses to seasonal rest.

J. Range Manage. 26:165-168.

Perennial grasses in southern Arizona increased more in 8 years under spring-summer (March-October) rest 2 years out of 3 than under continuous yearlong grazing or any of 13 other rest schedules.

MARTIN, S. CLARK.

1973.

A grazing system for semidesert ranges based on responses of grasses to seasonal rest.

Soc. Range Manage. [Boise, Idaho, Feb. 1973] Abstr. of Pap. 26:21.

Only one of three pastures is grazed at a time, and each gets (1) spring-summer rest 2 years out of 3, (2) winter grazing only between the two consecutive spring-summer rest periods, and (3) a full year of rest before each spring-summer grazing.

MARTIN, S. CLARK, AND HUDSON G. REYNOLDS.

1973.

The Santa Rita Experimental Range: Your facility for research on semidesert ecosystems.

J. Ariz. Acad. Sci. 8:56-67.

Describes the Range and its history, and gives the working ecologist an idea of the variety and scope of information available from 70 years of research on the impacts of grazing on the ecosystem, and relationships between flora, fauna, climate, and soils.

MARTIN, S. CLARK, AND DWIGHT R. CABLE.

1975.

Highlights of research on the Santa Rita Experimental Range.

p. 51-57. *In Arid Shrublands. Proc. Third Workshop of U.S./Aust. Rangelands Panel, Tucson, Ariz., Mar. 26-Apr. 5, 1973. 148 p.*

The Santa Rita, established in 1903, is the oldest research area of the U.S. Forest Service. Research on the interrelationships of organisms, attributes, and processes in semidesert ecosystems is intended to help landowners and administrators achieve land use goals to meet changing needs and demands of society.

MARTIN, S. CLARK.

1975.

Stocking strategies and net cattle sales on semidesert range.

USDA For. Serv. Res. Pap. RM-146, 10 p.

Simulating impacts of variable forage yields on income over a 29-year period indicates the cow herd should be maximized, cows should be bred to calve at age 2 and culled at age 8, and constant stocking at 90 percent of average proper stocking balances income against risk of overstocking.

MARTIN, S. CLARK.

1975.

Ecology and management of southwestern semidesert grass-shrub ranges: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-156, 39 p.

Vegetation on much semidesert range has shifted from grassland to brush since livestock ranching began. Shrub control, reseeding, and improved grazing management can reverse the trend. Grazing will continue to be a major use for semidesert range despite high land prices and increased recreational activity.

PAULSEN, HAROLD A., JR.

1975.

Range management in the central and southern Rocky Mountains: A summary of the status of our knowledge by range ecosystems.

USDA For. Serv. Res. Pap. RM-154, 34 p.

Summarizes a series of comprehensive reports on the seven recognized ecosystems: Semidesert grass-shrub, southwestern chaparral, pinyon-juniper, central Rockies ponderosa pine-bunchgrass, Arizona ponderosa pine-bunchgrass, mountain grassland, and alpine. Includes what is known, what can be recommended, and what additional information is needed for each ecosystem.

PEARSON, HENRY A.

1972.

Estimating cattle gains from consumption of digestible forage on ponderosa pine range.

J. Range Manage. 25:18-20.

In vitro digestibility measurements reduce the variability in estimating cattle gains from forage intake measurements. The daily digestible forage intake requirements of range cattle appear similar to the requirements of cattle in feedlots.

PEARSON, HENRY A.

1973.

Calculating grazing intensity for maximum profit on ponderosa pine range in northern Arizona.

J. Range Manage. 26:277-278.

The profit formula is based on forage production, digestibility and utilization, animal weight and daily gain, costs per animal day, and beef prices. Rangeland producing 500 to 1,000 pounds of forage per acre would produce maximum profit with moderate utilization.

SPRINGFIELD, H. W.

1976.

Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-160, 32 p.

The major problem in the pinyon-juniper type is widespread deterioration of the range resources due to overgrazing and increases in tree density. General guidelines are available for

judging the condition and grazing management of pinyon-juniper ranges, as well as for deciding where and how to control trees.

THILENIUS, JOHN F.

1975.

Alpine range management in the western United States--principles, practices, and problems: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-157, 32 p.

Reviews the present knowledge on the ecology and management of the alpine zone in western North America; describes the characteristics of the alpine; covers the unique ecology of the high-elevation, cold-dominated, alpine ecosystems; and discusses their management, with emphasis on the range resource and its relationship with other uses.

TURNER, GEORGE T., AND HAROLD A. PAULSEN, JR.
1976.

Management of mountain grasslands in the central Rockies: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-161, 24 p.

Knowledge is generally adequate for proper grazing management of these grasslands, but management and improvement costs tend to be relatively high because of their remoteness. Suggested improvements to increase range usability, improve forage production, and control livestock must be coordinated with water and timber production, and wildlife and recreation needs.

WARD, DONALD E.

1975.

Seasonal weight changes of cattle on semidesert grass-shrub ranges.

J. Range Manage. 28:97-99.

Average cow weights, on semidesert grass-shrub ranges in southern Arizona, increased slightly following spring greenup, but major weight gains began with summer forage and continued into November. Major weight losses were at calving time in December and January.

Range Improvement

ALDON, EARL F.

1972.

Critical soil moisture levels for field planting fourwing saltbush.

J. Range Manage. 25:311-312.

Survival was at least 80 percent when alluvial field sites had soil moisture levels of at least 14 percent by weight or were at tensions between 1/3 and 2 atmospheres.

ALDON, EARL F., AND GEORGE GARCIA.

1972.

Vegetation changes as a result of soil ripping on the Rio Puerco in New Mexico.

J. Range Manage. 25:381-383.

Soil ripping effectively reduced runoff and caused a favorable shift in forage production from galleta to alkali sacaton. Ripping effects on runoff are shortlived, but forage production patterns may persist for 10 years.

ALDON, EARL F.

1975.

Establishing alkali sacaton on harsh sites in the Southwest.

J. Range Manage. 28:129-132.

Because of critical establishment requirements, seeds of alkali sacaton (*Sporobolus airoides*) must be planted when both soil moisture and probability of rain are high. Large seeds should be mulched to maintain moisture and darkness.

ALDON, EARL F., AND H. W. SPRINGFIELD.

1975.

Using paraffin and polyethylene to harvest water for growing shrubs.

p. 251-257. *In Proc. Water Harvesting Symp., Phoenix, Ariz., Mar. 26-28, 1974. ARS W-22, 329 p.*

Paraffin and polyethylene catchments were equally effective in harvesting runoff water from small storms in the semiarid Southwest. Soil moisture remained higher and shrub transplants grew better under both treatments, which caught an extra 0.75 inch of water during the summer rainy season.

CABLE, DWIGHT R.

1972.

Fourwing saltbush revegetation trials in southern Arizona.

J. Range Manage. 25:150-153.

Establishment and survival of saltbush was much higher on a creosotebush site, where sandy loam soil was calcareous, than on a mesquite site, where neutral sandy loam surface soil was underlain with clay or clay loam.

CABLE, DWIGHT, R., AND S. CLARK MARTIN.

1973.

Invasion of semidesert grassland by velvet mesquite and associated vegetation changes.

J. Ariz. Acad. Sci. 8:127-134.

Even with the strong deterrent of a good stand of perennial grass, velvet mesquite numbers are increasing significantly. Inevitably, gradual size and density increases of mesquite will drastically reduce perennial grass production. Prevention at minimum cost requires early and vigorous control.

HAFERKAMP, M. R., AND P. O. CURRIE.

1973.

Effects of fertilizer on root strength of Sherman big bluegrass (*Poa ampla* Merr.).

Agron. J. 65:511-512.

Pulling of plants by grazing animals has been a common problem on Sherman big bluegrass pastures in Colorado. Tensions required for pullup in the greenhouse were correlated with root weight, and significantly increased with N fertilization.

KNIGHT, DENNIS H.,* AND JOHN THILENIUS.

1975.

Vegetation ecology.

p. 37-59. *In The Medicine Bow ecology project, final report, February 28, 1975. D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.*

Reviews the literature on vegetation ecology of the Medicine Bow mountains. Vegetation probably has not changed much since glaciation 8,000 years ago. Primary questions raised relate to effects of fire control and winter precipitation management on vegetation patterns. (Entire report available from NTIS, 397 p., \$3.)

MARTIN, S. CLARK, AND DWIGHT R. CABLE.

1974.

Managing semidesert grass-shrub ranges: Vegetation responses to precipitation, grazing, soil texture, and mesquite control.

U. S. Dep. Agric. Tech. Bull. 1480, 45 p.

In a 10-year study near Tucson, Ariz., perennial grasses increased in response to favorable rainfall and mesquite control, and did better on fine- than on coarse-textured soils. Because of heavy spring use, grazing November-April was less favorable for perennial grasses than May-October or yearlong grazing.

MARTIN, S. CLARK, JOHN L. THAMES,* AND ERNEST B. FISH.*

1974.

Changes in cactus numbers and herbage production after chaining and mesquite control.

Prog. Agric. Ariz. 26(6):3-6.

In 1974, 4 years after cabling, cholla cactus numbers were less than 10 percent of original, but pricklypear was reduced by less than 15 percent. Perennial grass production was increased more by killing mesquite trees with diesel oil than by cabling.

SPRINGFIELD, H. W.

1972.

Mulching improves survival and growth of cercocarpus transplants.

USDA For. Serv. Res. Note RM-220, 4 p.

After 2 years, plants mulched with black plastic had survived and grown better than those planted in basins. Best growth, by far, resulted from using plastic mulch on a chemically prepared site, and was attributed to additional soil moisture and reduced weed competition.

SPRINGFIELD, H. W.

1972.

Using mulches to establish woody chenopods.

p. 382-391. *In Wildland shrubs-their biology and utilization. USDA For. Serv. Gen. Tech. Rep. INT-1, 494 p.*

Mulches, both natural and artificial, should be considered for establishing shrubs in difficult environments. From the standpoint of ease of application, petroleum mulches offer considerable promise for modifying temperatures in the seed zone, and conserving soil moisture.

THILENIUS, JOHN F., DIXIE R. SMITH, AND GARY R. BROWN.

1974.

Effect of 2,4-D on composition and production of an alpine plant community in Wyoming.

J. Range Manage. 27:140-142.

Use of 2,4-D almost completely eliminated *Geum rossii*. The graminoid:forb ratio of the vegetation was altered from approximately 3:7 to 8:2 without appreciably changing total standing crop or its digestible dry matter content. Resurgence of forbs could not be detected up to 4 years after treatment.

THILENIUS, JOHN F., AND GARY R. BROWN.

1974.

Long-term effects of chemical control of big sagebrush.

J. Range Manage. 27:223-224.

Ten years after spraying with 2,4-D, canopy cover of big sagebrush was 8-42 percent of pretreatment levels, herbage production was below pretreatment levels with the proportion of graminoids about equal to that prior to spraying. Effects of grazing deferment for 3 years after spraying could not be detected.

THILENIUS, JOHN F., GARY R. BROWN, AND C. COLIN KALTENBACH.*

1975.

Treating forb-dominated subalpine range with 2,4-D: Effects on herbage and cattle diets.

J. Range Manage. 28(4):311-315.

Treatment changed the grass:forb ratio from 27:73 to 81:19, but had no influence on total herbage production. Steers ate significantly more grass only the first 2 years after treatment. Steers grazing sprayed units gained an average of 2.5 lb/day; those grazing unsprayed units 2.4.

WARD, DONALD E., AND S. CLARK MARTIN.

1972.

Tanglehead--a dual purpose grass.

Ariz. Cattlelog 28(8):18-20.

Tanglehead is most valuable as emergency forage and as a gully healer. In the long run, its value as a gully healer may be the more important role.

Reclamation Techniques

ALDON, EARL F.
1973.

Revegetating disturbed areas in the semiarid Southwest.

J. Soil Water Conserv. 28:223-225.

Fourwing saltbush and alkali sacaton, excellent soil stabilizers and nutritious forage plants, can be established on floodplain areas with less than 10 inches annual rainfall, if prescribed steps are followed. Sacaton is seeded, while saltbush seedlings are transplanted. Timing is critical.

ALDON, EARL F., O. D. KNIPE, AND GEORGE GARCIA.
1973.

Revegetating devastated sites in New Mexico with western wheatgrass transplants.

USDA For. Serv. Res. Note RM-243, 3 p.

Western wheatgrass (*Agropyron smithii* Rydb.) survived well and produced daughter plants from rhizomes during the first year when good seeds were grown to 3-month-old transplants, then transferred to sandy or clay loam sites at elevations of around 7,500 feet.

ALDON, EARL F., AND H. W. SPRINGFIELD.
1973.

Revegetating coal mine spoils in New Mexico: A laboratory study.

USDA For. Serv. Res. Note RM-245, 4 p.

Emergence and early growth of mountain rye and fourwing saltbush were studied in untreated 3-year-old mine spoils, and in spoils to which organic matter or fertilizer had been added under greenhouse conditions. Emergence and growth were satisfactory from untreated spoils; adding amendments had no effect on seedling emergence or early growth.

ALDON, EARL F.
1974.

Problems and techniques in revegetating coal mine spoils in New Mexico.

Soc. Range Manage. [Tucson, Ariz., Feb. 1974] Abstr. of Pap. 27:27.

Tests thus far have revealed no toxicity to the germination or early growth of native shrubs and grasses. Fertilizer and soil amendments had no effect on seedling emergence or first month's growth, but fertilizer is increasing growth after 3 months.

ALDON, EARL F., H. W. SPRINGFIELD, AND GEORGE GARCIA.
1975.

Can soil amendments aid revegetation of New Mexico coal mine spoils?

USDA For. Serv. Res. Note RM-292, 7 p.

Adding amendments did not improve seedling emergence in greenhouse tests with mountain rye, fourwing saltbush, and western wheatgrass. Shredded bark depressed herbage yields, especially where no fertilizer was supplied. Fertilizer consistently increased yield. Topsoil was not always a better growth medium than spoil.

ALDON, EARL F.
1975.

Endomycorrhizae enhance survival and growth of fourwing saltbush on coal mine spoils.

USDA For. Serv. Res. Note RM-294, 2 p.

Atriplex canescens is a valuable shrub for domestic livestock and wildlife, and protects soil from wind and water erosion in semiarid areas, beneficial features for coal mine spoil reclamation. Inoculation of saltbush seedlings with *Glomus mosseae* improves transplanting success.

ALDON, EARL F.
1975.

Techniques for establishing native plants on coal mine

spoils in New Mexico.

p.21-28. In Third Symp. on Surf. Min. and Reclam., Vol. 1. NCA/BCR Coal Conf. and Expo II [Louisville, Ky., Oct. 1975.] Natl. Coal Assoc., Wash., D.C. 243 p.

Direct seeding of native species has succeeded when weather was favorable, but precipitation often is deficient and erratic. Irrigation during the first year is necessary for plant establishment where precipitation averages less than 8 inches. The drip system appears effective. Water harvesting can provide supplemental water on drier sites.

ALDON, EARL F., AND H. W. SPRINGFIELD.
1975.

Problems and techniques in revegetating coal mine spoils in New Mexico.

p. 122-132. In Practices and problems of land reclamation in western North America. Mohan K. Wali, ed. Univ. N.D. Press, Grand Forks. 196 p.

Plant establishment on graded spoils is possible, but sometimes difficult. Irrigation is essential the first year. Sprinkler and drip irrigation have been tested, as has water harvesting to maintain vegetation. Also being studied are organic and chemical spoil amendments and mycorrhizae. Native plant species seem best for reclamation.

ALDON, EARL F., H. W. SPRINGFIELD, AND DAVID G. SCHOLL.
1976.

Fertilizer response of alkali sacaton and fourwing saltbush grown on coal mine spoil.

USDA For. Serv. Res. Note RM-306, 4 p.

Adding N or P alone at any level had little effect on greenhouse yields. Combined application of N and P, however, increased yield two to three times in both species. Yield responses differed between species depending on both relative amount of N or P in the mix and the time of application.

ORR, HOWARD K.
1975.

Mine spoil reclamation research at the Belle Ayr mine, northeast Wyoming.

Proc. Fort Union Coal Field Symp., vol. 3: Reclamation section. p. 304-307. [Mont. Acad. Sci., Billings, Apr. 1975.]

Revegetation research with shrubs and trees has been moderately successful. Moisture is the most apparent limiting factor. Risk of failure in any year is high enough to warrant such added efforts as trickle irrigation, containerized planting stock, mulching.

THILENIUS, JOHN F., AND GARY B. GLASS.*
1974.

Surface coal mining in Wyoming: Needs for research and management.

J. Range Manage. 27:336-341.

Wyoming ranks second in the nation in strippable coal resources, with at least 18.9 billion recoverable tons. Mining it could disturb about 590 square miles. Renewable resource research and management face a challenge to allow use of the coal without lasting detrimental effects on other resources.

YAMAMOTO, TERUO.
1975.

Trend surface analysis of Powder River Basin, Wyoming-Montana.

Proc. Fort Union Coal Field Symp., vol. 3: Reclamation section. p. 280-288. [Mont. Acad. Sci., Billings, Apr. 1975.]

Trend surface analysis is a mathematical technique which provides insights into strip-mine reclamation questions such as: What are feasible and esthetically pleasing surface drainage patterns and landscape designs? What changes can be expected in surface and subsurface hydrology?

YAMAMOTO, TERUO.
1975.

Coal mine spoil as a growing medium: AMAX Belle Ayr South Mine, Gillette, Wyoming.
p. 49-61. *In* Third Symp. on Surf. Min. and Reclam., Vol. 1. NCA/BCR Coal Conf. and Expo II [Louisville, Ky., Oct. 1975.] Natl. Coal Assoc., Wash., D.C. 243 p.

Although slightly more saline than surrounding soils, spoil salinity was not enough to severely limit plant growth or survival. General nutrient status was low, but loamy texture was favorable. Favorable growth is expected on these spoils.

Range Pests

LAYCOCK, W. A., AND B. Z. RICHARDSON.*
1976.

The role of pocket gophers on subalpine rangelands. Soc. Range Manage. [Omaha, Nebr., Feb. 1976] Abstr. of Pap. 29:43.

Recovery on depleted high-elevation rangelands is very slow. Gophers influence rate of vegetal succession on overgrazed rangeland, and have a small effect on nutrient content and porosity of soils.

TURNER, G. T., R. M. HANSEN,* V. H. REID,* H. P. TIETJEN,* AND A. L. WARD.
1973.

Pocket gophers and Colorado mountain rangeland. Colo. State Univ. Exp. Stn. Bull. 554S, 90 p.

Summarizes research by 18 scientists over a 15-year period. Results are presented in separately authored chapters on distribution and adaptation; population biology; food habits and competition; effects on the range; 2,4-D, vegetation, and pocket gophers; and control.

Habitat Evaluation: Mammals

BOEKER, ERWIN L.,* VIRGIL E. SCOTT,* HUDSON G. REYNOLDS, AND BYRON A. DONALDSON.*
1972.

Seasonal food habits of mule deer in southwestern New Mexico.

J. Wildl. Manage. 36:56-63.

Deer apparently subsist satisfactorily on a diet dominated by browse species, of which birchleaf mountainmahogany and oaks are most important. Forbs are an important supplement, especially during years with favorable spring and summer rain.

CLARY, WARREN P.
1972.

A treatment prescription for improving big game habitat in ponderosa pine forests. p. 25-28. In 16th Annu. Ariz. Watershed Symp. [Phoenix, Ariz., Sept. 1972] Proc. Ariz. Water Comm. Rep. 2, 43 p. Phoenix, Ariz.

Treatments are designed to determine possible differences in wildlife responses to created openings in managed and unmanaged forests. One-fifth of the managed timber area will be in permanent openings of 1 to 10 acres; one-third of unmanaged forest will be in such openings.

FFOLIOTT, PETER F.,* WARREN P. CLARY, AND FREDERIC R. LARSON.
1976.

Observations of beaver activity in an extreme environment. Southwest. Nat. 21(1):131-133.

Beaver were observed near small perennial pools formed in normally dry drainages dissecting desertscrub and riparian hardwood vegetation types on Dry Beaver drainage in north-central Arizona.

GOODWIN, GREGORY A.
1975.

Seasonal food habits of mule deer in southeastern Wyoming.

USDA For. Serv. Res. Note RM-287, 4 p.

Fecal analysis showed mule deer diets consisted of 87.6 percent browse, 5.6 percent graminoids, and 6.6 percent forbs. Deer ate as much as 19 percent graminoids in May, 36 percent forbs in June, and 96 percent browse in winter. Most important were big sagebrush, antelope bitterbrush, and true mountainmahogany.

JOHNSON, PHIL.
1974.

Food for deer.

Colo. Outdoors 23(1):12-14.

In 1967, the Forest Service, Colorado Division of Wildlife, and Colorado State University began cooperative research to find improved methods for managing deer winter ranges in the central Rockies. This article briefly describes the research conducted by each agency with emphasis on Forest Service nutrition and food production studies.

KUFELD, ROLAND C.,* O. C. WALLMO, AND CHARLES FEDDEMA.
1973.

Foods of the Rocky Mountain mule deer.

USDA For. Serv. Res. Pap. RM-111, 31 p.

Literature on food habits was reviewed to compile listings of reported foods of this species throughout its range. Relative importance of a plant species is indicated on the basis of its contribution to the diet in 99 studies.

KUNDAELI, JOHN N.,* AND HUDSON G. REYNOLDS.
1972.

Desert cottontail use of natural and modified pinyon-juniper woodland.

J. Range Manage. 25:116-118.

Pinyon-juniper woodland is often cleared to improve grazing for livestock. In southern New Mexico, cottontail habitat can be maintained during clearing operations by preserving some combination of 70-90 down, dead trees and living shrubs per acre.

PATTON, DAVID R.
1974.

Patch cutting increases deer and elk use of a pine forest in Arizona.

J. For. 72:764-766.

Deer and elk benefited when harvesting of ponderosa pine--the major commercial timber species in the Southwest--made a monotonous forest more diverse. Small, irregular, clearcut patches adjacent to scattered stands of saplings, poles, and sawtimber produced increases in grasses, forbs, and browse.

PATTON, DAVID R.
1975.

Nest use and home range of three Abert squirrels as determined by radio tracking.

USDA For. Serv. Res. Note RM-281, 3 p.

Abert squirrels have and use more than one nest in their home range. Three squirrels used 2, 5, and 6 nests in areas of 30, 10, and 85 acres, respectively.

PATTON, DAVID R.
1975.

Abert squirrel cover requirements in southwestern ponderosa pine.

USDA For. Serv. Res. Pap. RM-145, 12 p.

Describes characteristics of ponderosa pine trees and stands selected by the Abert squirrel for cover, including basal area, tree density and size, tree vigor, dominance and age class, nest location, and nest tree density.

PATTON, DAVID R., AND PETER F. FFOLLIOTT.*

1975.

Selected bibliography of wildlife and habitats for the Southwest.

USDA For. Serv. Gen. Tech. Rep. RM-16, 39 p.

Contains 390 selected references on research and management of important wildlife species and habitats in Arizona and New Mexico, covering a period from 1913 to early 1975. A subject index is keyed to an alphabetical list of authors.

RATCLIFF, THOMAS D.,* DAVID R. PATTON, AND PETER F. FFOLLIOTT.*

1975.

Ponderosa pine basal area and the Kaibab squirrel.

J. For. 73:284-286.

A measured squirrel population index was most consistently associated with basal area of ponderosa pine, including all pines and pines over 6 inches d.b.h. A model for assessing quality of squirrel habitat was formulated.

REGELIN, WAYNE L., AND OLOF C. WALLMO.

1975.

Carbon black increases snowmelt and forage availability on deer winter range in Colorado.

USDA For. Serv. Res. Note RM-296, 4 p.

Use of carbon black offers potential for increasing the availability of deer forage on winter ranges. On slopes with a southern exposure, over 40 cm of snow was melted to bare ground in February when air temperature averaged -8.8C during daylight hours.

REYNOLDS, HUDSON G.

1974.

Habitat research...cornerstone in management.

N. Mex. Wildl. 19(1):28-30.

To survive and reproduce, each species of wildlife requires specific living conditions or places of feeding, breeding, resting, playing, and refuge. If research can determine the kind, amount, and dispersion of plants to supply these habitat requirements, wildlife populations are assured.

THILENIUS, JOHN F.

1972.

Classification of deer habitat in the ponderosa pine forest of the Black Hills, South Dakota.

USDA For. Serv. Res. Pap. RM-91, 28 p.

The ponderosa pine forest was classified into 13 habitat units by cluster analysis of a similarity matrix based on the vegetation, soil, and site attributes of 100 randomly located sample stands. Habitat units were defined at a minimum similarity of 60 percent. The comparative use of the habitats by deer was evaluated by analysis of variance of long-term (9 years) data on deer pellet group densities in the sample stands.

TURKOWSKI, FRANK J.

1975.

Dietary adaptability of the desert cottontail.

J. Wildl. Manage. 39(4):748-756.

Desert cottontails apparently can survive mainly on dry grasses and forbs, using cactus and forbs with high moisture contents as a source of water. Grasses contributed 38 percent of the dietary bulk, forbs 41 percent, and shrubs 21; 43 plant species or genera were identified in stomach contents.

URNES, PHILIP J.

1974.

Deer use changes after root plowing in Arizona chaparral.

USDA For. Serv. Res. Note RM-255, 8 p.

Deer spent one-fourth to one-half as much time on root-plowed chaparral pastures seeded to lovegrass as in adjacent brushfields. Although high-quality forbs increased greatly on treated southerly exposures, deer showed no apparent preference for those slopes.

WALLMO, OLOF C., WAYNE L. REGELIN, AND DONALD W. REICHERT.

1972.

Forage use by mule deer relative to logging in Colorado.

J. Wildl. Manage. 36:1025-1033.

A lodgepole pine, spruce-fir forest was clearcut in narrow strips alternating with uncut strips. Forage production 15 years later was 47 percent greater on cut strips. Tame deer obtained 63.3 percent of their forage from cut strips, 27.4 percent from uncut strips, and 9.3 percent from logging roads.

WALLMO, OLOF C.

1975.

Important game animals and related recreation in arid shrublands of the United States.

p. 98-107. In *Arid Shrublands. Proc. Third Workshop of U.S./Aust. Rangelands Panel, Tucson, Ariz., Mar. 26-Apr. 5, 1973.* 148 p.

Reviews environmental and biological factors that affect welfare of game animals, and identifies some aspects of their use as a recreational resource. Progressive loss of wildlands probably is the major factor influencing abundance and diversity of wildlife in western U.S.

WARD, A. LORIN.

1973.

Sagebrush control with herbicide has little effect on elk calving behavior.

USDA For. Serv. Res. Note RM-240, 4 p.

Elk did not change their calving behavior or feeding habits on a site where 96.7 percent of the big sagebrush (*Artemisia tridentata*) cover had been killed with 2 pounds acid equivalent of 2,4-D herbicide.

WARD, A. L., K. DIEM,* AND R. WEEKS.*

1975.

The impact of snow on elk.

p. 105-133. In *The Medicine Bow ecology project, final report, February 28, 1975.* D. H. Knight, coord., Univ. Wyo., Laramie, for Div. Atmos. Water Resour. Manage., Bur. Reclam., U.S. Dep. Int., Denver, Colo.

Elk can paw through relatively deep light snow for food. Ice layers and deeper snow create difficulties. If target areas for increasing snow through weather modification are above elk winter range, 30 percent more snow accumulation should have no adverse effects. (Entire report available from NTIS, 397 p., \$3.)

Habitat Evaluation: Birds and Fish

BEAVER, DONALD L.,* AND PAUL H. BALDWIN.*

1975.

Ecological overlap and the problem of competition and sympatry in the western and Hammond's flycatchers.

Condor 77(1):1-13.

The western flycatcher displaced the Hammond's to some degree from aspen-conifer habitat. Thus the western flycatcher appears to be the superior competitor in this area (Wet Mountains of southern Colorado). Local coexistence is most likely temporary and unstable.

EVANS, KEITH E., AND ROGER R. KERBS.

1972.

Some birds of Jackson County, South Dakota.

S. D. Bird Notes 24(4):76-77, 81. (Whole No. 95).

During 98 visits to 12 study ponds in a 6-year period, 13,432 waterfowl, 1,066 shorebirds, and 62 other bird species were counted.

LENNARTZ, MICHAEL R.,* AND ARDELL J. BJUGSTAD.
1975.

Information needs to manage forest and range habitat for nongame birds.
p. 328-333. *In Proc. Symp. Manage. For. Range Habitats for Nongame Birds* [Tucson, Ariz., May 1975]. USDA For. Serv. Gen. Tech. Rep. WO-1, 343 p. Wash., D.C.

Highlights the management information and research needs as pointed out in previous papers of this Proceedings, and comments submitted from land managers. A consensus is implied that management of nongame birds and their habitats is a relatively new resource issue, and available information is badly scattered.

SCHROEDER, MAX H.,* AND DAVID L. STURGES.
1975.

The effect on the Brewer's sparrow of spraying big sagebrush.

J. Range Manage. 28(4):294-297.

Three Brewer's sparrow nests in plants sprayed with 2,4-D were apparently unaffected. Sparrow use of a sprayed sagebrush stand 1 and 2 years after spraying, however, was 67 and 99 percent lower, respectively, than on an unsprayed stand; no evidence of nesting was found on the sprayed stand.

SCOTT, VIRGIL E.,* AND DAVID R. PATTON.
1975.

Cavity-nesting birds of Arizona and New Mexico forests.

USDA For. Serv. Gen. Tech. Rep. RM-10, 52 p.

Summarizes published data and personal observations of nesting and food habits of 41 species of cavity-nesting birds in five southwestern forest types.

Wildlife Anatomy, Physiology, Reproduction

EVANS, KEITH E., AND AARON N. MOEN.*
1975.

Thermal exchange between sharp-tailed grouse (*Pedioecetes phasianellus*) and their winter environment.

Condor 77(2):160-168.

Maintenance metabolic rate, weight change features, effective surface area, thermal transfer properties, thermoregulatory behavior, wind velocity, and ambient temperature were analyzed to predict energy requirements.

NAGY, J. G.,* AND W. L. REGELIN.
1975.

Comparison of digestive organ size of three deer species.

J. Wildl. Manage. 39(3):621-624.

Roe (*Capreolus capreolus*), red (*Cervus elaphus*), and fallow deer (*Cervus dama*) collected in Hungary were compared. The relative rumen-reticulum tissue weight as a percentage of body weight was similar for all three species. As species' body size increased, relative weight of omasal tissue increased, and abomasum tissue decreased.

REYNOLDS, HUDSON G.
1972.

An albino Gambel quail from southern Arizona.
J. Ariz. Acad. Sci. 7:46.

This record, a male collected Dec. 17, 1970 near Helvetia, is the first known report of albinism in Gambel quail.

REYNOLDS, HUDSON G., AND FRANK TURKOWSKI.
1972.

Reproductive variations in the round-tailed ground squirrel as related to winter rainfall.

J. Mammal. 53: 893-898.

Dates of inception of breeding and number of embryos per litter are strongly correlated with the 2- to 5-month rainfall period preceding the February through April breeding season.

SEVERSON, KIETH E., HAROLD E. MESSNER, AND DONALD R. DIETZ.

1972.

Two-headed white-tailed deer fetus.

Am. Midl. Nat. 88:464-465.

This paper reports the occurrence and physical characteristics of a two-headed white-tailed deer (*Odocoileus virginianus dakotensis* Goldman and Kellogg) fetus taken from a 3-1/3-year-old doe in western South Dakota.

WATKINS, ROSS K., AND PHILIP J. URNESS.
1972.

Maxillary canine and supernumerary incisors in Arizona Coues white-tailed deer.

Southwest. Nat. 17:211-213.

No earlier reports of either dental anomaly have been found in the literature for this race. Apparently it does not follow the general pattern of increased incidence of maxillary canines in white-tailed deer populations at southern latitudes.

Wildlife Nutrition

DIETZ, DONALD R.
1972.

Nutritive value of shrubs.

p. 289-302. *In Wildland shrubs--their biology and utilization.* USDA For. Serv. Gen. Tech. Rep. INT-1, 494 p.

Shrubs are important sources of protein, carbohydrate, and minerals for most classes of wild herbivores, especially during winter. Shrubs are highly digestible during plant growth, but become more difficult to digest as the cell walls become lignified.

EVANS, KEITH E.
1972.

Energetics of sharp-tailed grouse during winter.

Soc. Range Manage. [Wash., D.C., Feb. 1972] Abstr. of Pap. 25:24.

Winter energetics were analyzed within a mathematical framework for predicting energy requirements, feed intake, and weight changes at varying temperatures and wind velocities, thus establishing a base for management decisions involving food and cover for sharp-tails on northern Great Plains ranges.

EVANS, KEITH E., AND DONALD R. DIETZ.
1974.

Nutritional energetics of sharp-tailed grouse during winter.

J. Wildl. Manage. 38:622-629.

In ad libitum feeding trials, adult grouse ingested more fleshy hawthorn berries than any of six other foods. Silver buffaloberry was the best native winter food tested. Food consumed provided metabolizable energy in excess of 1.5 times basal metabolic rate.

MC CULLOCH, CLAY Y.,* AND PHILIP J. URNESS.
1973.

Deer nutrition in Arizona chaparral and desert habitats.

Ariz. Game and Fish Dep. Spec. Rep. 3, 68 p.

This three-part study--seasonal diets of mule and white-tailed deer, chemical analyses and in vitro digestibility of seasonal deer forages, and nutritional value of seasonal deer diets--indicates forage quality is not responsible for recent poor fawn survival. Inhibited phosphorus metabolism is suspect, however.

NAGY, J. G.,* AND O. C. WALLMO.
1973.

Deer nutrition problems in the U.S.A.

Proc. World Exhib. Hunting, Int. Sci. Conf. Game Manage., [Budapest, Sept. 1971] Sect. 1, p. 59-68. Univ. Press, Sopron, Hung.

Reviews the history of deer population and habitat management problems in the U.S., the development of knowledge of nutritional requirements of deer, and application of such knowledge to habitat management.

REGELIN, WAYNE L., OL F C. WALLMO, JULIUS G. NAGY,* AND DONALD R. DIETZ.

1974.

Effect of logging on forage values for deer in Colorado. J. For. 72:282-285.

Crude protein content, moisture content, and digestibility did not differ statistically between clearcut and uncut strips. Because of greater species diversity and plant productivity, and because deer spent more time grazing in clearcut strips, they obtained over twice as much of their crude protein and digestible dry matter there.

URNESS, P. J., D. J. NEFF,* AND R. K. WATKINS.
1975.

Nutritive value of mule deer forages on ponderosa pine summer range in Arizona.

USDA For. Serv. Res. Note RM-304, 6 p.

Chemical analyses and apparent in vitro dry matter digestibilities were obtained for monthly diets. Relative values were calculated, based on nutrient contents and percentage composition in the diet. These data will help land managers assess impacts of vegetation management on mule deer habitat, and in designing habitat improvements.

URNESS, P. J., D. J. NEFF,* AND J. R. VAHLE.
1975.

Nutrient content of mule deer diets from ponderosa pine range.

J. Wildl. Manage. 39(4):670-673.

Nutritional quality declined sharply from high levels in spring to moderate by late summer, but not enough to suggest deficiencies. Overall quality of summer diets was quite good. Very high values during late gestation should assure good milk production and optimum fawn production.

Experimental and Analytical Techniques

CUPAL, JERRY J., A. LORIN WARD, AND RICHARD W. WEEKS.*

1974.

A repeater type biotelemetry system for use on wild big game animals.

Eleventh Annu. Rocky Mt. Bioeng. Symp. and Eleventh Int. ISA Biomed. Sci. Instrum. Symp. [Colo. Springs, Colo., Apr. 1974] Proc., Biomed. Sci. Instrum. 10:145-152.

The telemetry system consists of an implanted heat-flow-rate sensing transmitter, a repeater-type neck collar which sensed the pulses from the implant and retransmitted them, and a portable receiving station consisting of a receiver, decoding circuitry, and analog chart recorder. Field experience has been short but satisfactory.

DIEM, KENNETH L.,* A. LORIN WARD, AND JERRY J. CUPAL.*

1974.

Cameras as remote sensors of animal activities.

XIth Int. Congr. Game Biol. [Stockholm, Sweden, Sept. 1973] Pap., 10 p.

A Super-8 mm remote time-lapse system combines simplicity, durability, economy, and good image characteristics, although 35 mm systems may be more appropriate in some instances. Careful construction and electronic circuitry are critical.

HILLER, PAUL K.,* RICHARD W. WEEKS,* JERRY J. CUPAL, AND A. LORIN WARD.

1974.

An automatic wildlife tracking system.

Eleventh Annu. Rocky Mt. Bioeng. Symp. and Eleventh Int. ISA Biomed. Sci. Instrum. Symp. [Colo. Springs, Colo., Apr. 1974] Proc. Biomed. Sci. Instrum. 10:157-160.

Describes development work on a system to be used in airplanes or four-wheel-drive vehicles. It is capable of tracking a low-duty cycle pulse signal, and gives direction on a pulse-by-pulse basis. Performance is not yet entirely satisfactory, but proves validity of concepts.

KOVNER, J. L., AND S. A. PATIL.

1974.

Properties of estimators of wildlife population density for the line transect method.

Biometrics 30:225-230.

The variance of several estimators of the population density based on the line transect method of distance sampling are studied under exponential sighting probability. The estimator suggested by Gates (1969) is shown to be minimum variance unbiased estimator. Efficiency of other estimators is obtained with respect to this estimator.

LAVIN, FRED,* AND O. D. KNIPE.

1975.

Drip pan for field plot sprinkle irrigation.

J. Range Manage. 28:155-157.

This drip pan, developed for uniformly irrigating small field plots in remote locations by simulated rainfall, is inexpensive to build, easily operated by one man, sturdy, portable, clog resistant, and adaptable to a wide variety of conditions.

PARKER, H. DENNISON, JR., AND JAMES C. HARLAN.*
1972.

Solar radiation affects radiant temperatures of a deer surface.

USDA For. Serv. Res. Note RM-215, 4 p.

Variation in effective radiant temperature (ERT) of a deer hide, when sunlit and shaded, was measured with an infrared radiometer. Mean decrease in ERT was 18.3 C. in 120 seconds after shade was applied. Deer detection by an airborne thermal infrared scanner should be conducted during periods of no direct-beam solar radiation, that is, sunset to dawn.

PARKER, H. DENNISON, JR.

1972.

Environmental factors affecting detection of wild deer with an airborne thermal infrared scanner.

Soc. Range Manage. [Wash., D.C., Feb. 1972] Abstr. of Pap. 25:33.

Multiple regression analysis indicated air temperature was the environmental factor most closely associated with the effective radiant temperature (ERT) of deer, snow, sagebrush, rock, and bare soil. Solar radiation had a marked but highly variable effect. Thermal contrast between deer and snow was always in excess of 2C.

PARKER, H. DENNISON, JR., AND RICHARD S. DRISCOLL.

1972.

An experiment in deer detection by thermal scanning.

J. Range Manage. 25:480-481.

An airborne, thermal infrared scanner was tested for deer detection over penned mule deer (*Odocoileus hemionus hemionus*) near Fort Collins, Colorado. The animals were detected at 300- and 500-foot altitudes, but not at 1,000 feet.

PATTON, DAVID R., VIRGIL E. SCOTT,* AND ERWIN L. BOEKER.*

1972.

Construction of an 8-mm time-lapse camera for biological research.

USDA For. Serv. Res. Pap. RM-88, 8 p.

A time-lapse camera for use in biological research can be constructed from a super 8-mm movie camera. A single-frame release is activated through a solenoid controlled by an electronic timer. The unit is activated by a photo cell for daylight operation. Timing interval can be varied from 1/2 second to 60 minutes. With a 5-minute interval and 12 hours of daylight, one roll of film will last 25 days. The unit operates from a 6-volt d.c. power supply. Cost of camera, solenoid, and electronic timer is approximately \$165.

PATTON, DAVID R., DAVID W. BEATY,* AND RONALD H. SMITH.*

1973.

Solar panels: An energy source for radio transmitters on wildlife.

J. Wildl. Manage. 37:236-238.

A panel constructed of 24 commercial grade silicon cells is capable of charging a 7.5 volt (180 ma capacity) nickel-cadmium battery for day and night operation, or an electrolytic capacitor for day operation only. The panel measures 5.71 cm x 4.44 cm x .63 cm and costs \$55.

PATTON, DAVID R., HOWARD G. HUDAK,* AND THOMAS D. RATCLIFF.*

1976.

Trapping, anesthetizing, and marking the Abert squirrel.

USDA For. Serv. Res. Note RM-307, 2 p.

Folding live traps placed at 250-foot intervals on a 1,000-foot grid provide a density of approximately two traps per acre for capturing the Abert squirrel. Procedures are described for anesthetizing squirrels for physical examination. Squirrels are marked with ear tags and colored collars.

PIATT, J. R.,* AND H. W. SPRINGFIELD.

1973.

Tetrazolium staining of cliffrose embryos.

Proc. Assoc. Off. Seed Anal. 63:67-75.

Staining embryos for 2 hours in a 0.5 percent TTC solution at 40 degrees C gives near-optimum results in terms of rapidity and intensity of staining. Embryos must be almost completely stained a dark red to be considered germinable.

REICHERT, DONALD W.

1972.

Rearing and training deer for food habits studies.

USDA For. Serv. Res. Note RM-208, 7 p.

Wild does are trapped in winter. Fawns are left with the doe at least 12 hours to assure feeding of colostrum, but less than 24 hours. Reliance on the human trainer develops through bottle feeding and frequent contact. Training for field use requires 4 to 6 weeks.

TURNER, GEORGE T.

1972.

A new approach to estimating herbage moisture content.

J. Range Manage. 25:229-231.

Moisture contents of different species of range plants growing under generally similar conditions are closely related during the period of peak herbage development. From regression equations that express those relationships, moisture content of several species can be predicted within reasonable limits from the content of one or more associated species.

URESK, DANIEL W., DONALD R. DIETZ, AND HAROLD E. MESSNER.

1975.

Constituents of in vitro solution contribute differently

to dry matter digestibility of deer food species.

J. Range Manage. 28(5):419-421.

Apparent digestibility was lowest, 29 percent, for water alone, buffer alone, and buffer plus pepsin. Dry matter loss increased to 33 percent with buffer + alcohol + HCl. Highest apparent digestibility, 44 percent, was reached with the addition of white-tailed deer inoculum. HCl contributed significantly to digestion while pepsin did not.

WALLMO, O. C., R. B. GILL,* L. H. CARPENTER,* AND D. W. REICHERT.

1973.

Accuracy of field estimates of deer food habits.

J. Wildl. Manage. 37:556-562.

The 'grazing minutes' method of determining food habits was tested by observing tame mule deer at close range. Use of shrubs was overestimated, while grasses and forbs were underestimated. With the 'feeding site' method, use of shrubs and forbs was underestimated, while grasses were overestimated.

WEEKS, RICHARD W.,* A. LORIN WARD, AND JERRY CUPAL.*

1972.

A telemetry system for studying elk behavior in the Rocky Mountains.

Ninth Ann. Rocky Mt. Bioeng. Symp. and Tenth Int. ISA Biomed. Sci. Instrum. Symp. [Omaha, Nebr., May 1972] Proc., Biomed. Sci. Instrum. 9:177-181.

The electronic circuit design is a combination of multivibrator timing control and the Cochran or Squegging oscillator. The antenna chosen was a circular, half-wave dipole. The system has been used for 1 year on six cow elk in southeastern Wyoming.

WEEKS, RICHARD W.,* JERRY J. CUPAL,* AND A. LORIN WARD.

1972.

Telemetry tracking of summer transplanted elk in south central Wyoming.

Int. Telem. Conf. [Los Angeles, Calif., Oct. 1972] Proc. 1972:238-244.

Generally, elk are trapped and transplanted in winter. A telemetry system developed for use on elk is described, along with behavior of elk transplanted during summer. The rutting season appears to be an optimum time for transplanting elk.

Multiple Use Relations

CLARY, WARREN P., WILLIAM H. KRUSE, AND FREDERIC R. LARSON.

1975.

Cattle grazing and wood production with different basal areas of ponderosa pine.

J. Range Manage. 28(6):434-437.

Beef gain potential was maximum at zero basal area, and was one-third less when ponderosa pine was present at basal areas of 20 square feet per acre. The combined economic value of grazing and saw-log production would be maximum in tree stands having a basal area of about 45 to 60 square feet per acre.

FFOLIOTT, PETER F.,* AND DAVID R. PATTON.

1975.

Production-rating functions for Abert squirrels in southwestern ponderosa pine.

Wildl. Soc. Bull. 3(4):162-165.

Production-rating functions for Abert squirrel food and nest trees and for ponderosa pine tree volume were plotted against one another to form decisionmaking models for identifying conflicts between use. The graphs show competitive stages, where the value of one improves while the other declines.

MARTIN, S. CLARK.

1972.

Semidesert ecosystems--who will use them. How will we manage them.

Soc. Range Manage. [Wash., D.C., Feb. 1972] Abstr. of Pap. 25:16.

Maximum sustained production of forage and beef no longer is an adequate objective for management of southwestern semidesert ranges; nonrancher interests are claiming an increasing voice in their management. Recreational activities may supplement ranch income from livestock.

MARTIN, S. CLARK.

1975.

Why graze semidesert ranges?

J. Soil Water Conserv. 30(4):186-188.

Population increases are dramatically changing land use in the arid Southwest. Range livestock, however, require little fossil fuel to make high-quality food from forage that is otherwise uneconomical to harvest. Good grazing management can control erosion, and improve forage, wildlife habitat, esthetics, and recreation.

REYNOLDS, HUDSON G.

1972.

Wildlife habitat improvement in relation to watershed management in the Southwest.

p. 10-17. In 16th Annu. Ariz. Watershed Symp. [Phoenix, Ariz., Sept. 1972] Proc. Ariz. Water Comm. Rep. 2, 43 p. Phoenix, Ariz.

Describes treatment impacts on habitat, and wildlife responses in ponderosa pine, pinyon-juniper, chaparral, and riparian habitats. We can now recommend some constraints of watershed treatments that will improve wildlife habitat.

WARD, A. LORIN, JERRY J. CUPAL,* ALFRED L. LEA, CHARLES A. OAKLEY,* AND RICHARD W. WEEKS.*

1973.

Elk behavior in relation to cattle grazing, forest recreation and traffic.

North Am. Wildl. Nat. Resour. Conf. [Wash., D. C., Mar. 1973] Trans. 38:327-337.

Elk are compatible with cattle on range with adequate food, but apparently prefer to keep at least a half mile from out-of-vehicle recreationists. Elk were cautious about crossing major roads, but often grazed within 300 yards of Interstate 80.

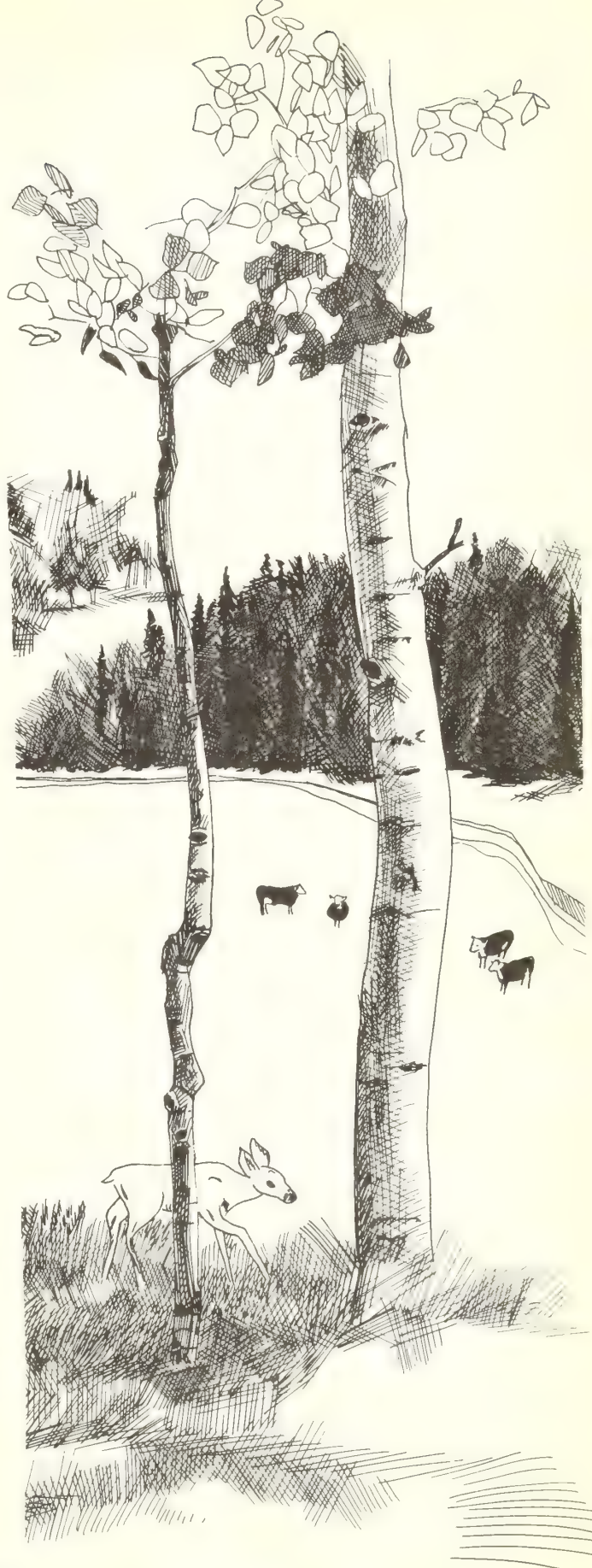
WARD, A. LORIN.

1973.

Elk behavior in relation to multiple uses on the Medicine Bow National Forest.

West. Assoc. State Game Fish Comm. [Salt Lake City, Utah, July 1973] Proc. 53:125-141.

Telemetry was used to monitor elk behavior in relation to multiple uses on the Medicine Bow National Forest in southern Wyoming. Elk and cattle appeared to be socially compatible where there is an adequate food supply. Traffic on Forest Service systems roads has little effect on elk activity, especially beyond 300 yards. Interstate 80 acts as a barrier to elk movement. Elk preferred to be at least one-half mile from people engaged in out-of-vehicle activity such as camping, picnicking, fishing, and harvesting timber.



RECREATION

*Private, State or Federal cooperator

Avalanches: See Avalanches, Snow Physics under WATERSHED MANAGEMENT

Recreationist Behavior

BROWN, PERRY J.,* BEVERLY L. DRIVER, AND GEORGE H. STANKEY.*

1976.

Human behavioral science and recreation management.

p. 53-63. *In* XVI IUFRO World Congr., Div VI, [Oslo, Norway, June 1976] *Proc. IUFRO Secr., Vienna, Austria.*

The usefulness of preference and behavior information is evaluated by asking: How does such information fit into recreation management decision processes? How well have researchers done in getting necessary data? What must now be done to make the contribution of behavioral science useful to recreation management?

DRIVER, B. L.

1975.

Quantification of outdoor recreationists' preferences. p. 165-187. *In* Research camping and environmental education. [Univ. Park, Pa., Dec. 1975]. *Penn State HPER Ser. 11*, 508 p.

Interprets recent research attempts to identify and measure specific types of experiences expected from particular activities. Different sets of factors influence these expectations, and the subsequent behavior they prompt.

DRIVER, B. L., AND JOHN R. BASSETT.*

1975.

Defining conflicts among river users: A case study of Michigan's Au Sable River.

Naturalist 26(1):19-23.

Perceptions of intensity and causes of conflicts between river users varied among trout fishermen, canoeists, livery owners, cottage owners, and people influential in local communities. To reduce conflicts, over half of all respondents favored developing additional rivers and distributing use more uniformly.

DRIVER, B. L., AND PERRY J. BROWN.*

1975.

A social-psychological definition of recreation demand, with implications for recreation resource planning.

p. 63-88. *In* Assessing demand for outdoor recreation, Nat. Res. Coun. Comm. on Assessment of Demand ... ed. NAS-NRC Rep. (unnumb.), Wash., D.C. 123 p.

Too little attention has been given to behavioral variables in recreation demand analyses. A general social-psychological model of recreation demand is proposed into which most theories and approaches to behavioral aspects of recreation behavior can be fitted, whether they are psychological, sociological, or physiological in nature.

Environmental Impacts

AUKERMAN, ROBERT,* AND WILLIAM T. SPRINGER.*
1976.

Effects of recreation on water quality in wildlands.

Eisenhower Consortium Bull. 2, 25 p.

This study indicates that recreational use is not at present a significant cause of bacterial water pollution; turbidity and dissolved-oxygen concentrations are also unaffected. Thus recreational opportunities may be provided near water with a minimum investment. Available as PB 251104, for \$4, from National Technical Information Service, Springfield, Virginia, 22151.

EISENHOWER CONSORTIUM FOR WESTERN ENVIRONMENTAL FORESTRY RESEARCH.

1975.

Man, leisure, and wildlands: A complex interaction. [Proc. First Eisenhower Consortium Res. Symp., Sept. 14-19, 1975, Vail, Colo.] *Eisenhower Consortium Bull.* 1, 286 p.

Limited number of copies available from the Rocky Mountain Station. Additional copies available for \$9.25 from: National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151. 1.

Environmental Amenities

BOSTER, RON S., AND TERRY C. DANIEL.*

1972.

Measuring public responses to vegetative management.

p. 38-43. *In* 16th Annu. Ariz. Watershed Symp. [Phoenix, Ariz., Sept. 1972] *Proc. Ariz. Water Comm. Rep. 2*, 43 p. Phoenix, Ariz.

Esthetic judgments of random color slides, taken in areas of ponderosa pine forest subjected to an array of vegetative manipulations from clearcut to essentially natural, were evaluated in terms of the psychologists' theory of signal detection. Results appear to be valid, reliable, and useful.

BOSTER, RON S.

1973.

On the criteria for and the possibility of quantifying the aesthetic aspects of water resource projects.

p. 6-21, *In* Toward a technique for quantifying aesthetic quality of water resources. Perry J. Brown, ed. [Colloq., Park City, Utah, Oct. 1972]. *Inst. Water Resour., Dep. Army, Corps Eng. PRWG-120-2*, 91 p. Utah State Univ., Logan.

Introduces the colloquim problem of quantifying aesthetic aspects of water resource projects, and discusses criteria that might serve to judge solutions to the problem, related research efforts, and the 'straw man' as a possible solution framework.

DANIEL, TERRY C.,* LAWRENCE WHEELER,* RON S. BOSTER, AND PAUL R. BEST, JR.*

1973.

Quantitative evaluation of landscapes: An application of signal detection analysis to forest management alternatives.

Man-Environ. Syst. 3:330-344.

Six ponderosa pine forest areas, each representing a different vegetative treatment, were presented in a series of color slides to individuals for detection and esthetic judgment of treatments. Signal detection analyses gave systematic and reliable indices of observers' reactions to different forest landscapes.

RESOURCE ASSESSMENT AND ECONOMICS

*Private, State or Federal cooperator

Assessment (Resource Inventories, Techniques)

DRISCOLL, R. S., P. O. CURRIE, AND M. J. MORRIS.
1972.

Estimates of herbaceous standing crop by microdensitometry.

Am. Soc. Photogramm. Annu. Meet. [Wash., D. C., Mar. 1972] Proc. 38:358-364.

Green standing herbage of seeded big bluegrass was estimated from large-scale color infrared aerial photos. Because of heterogeneous plant species composition, however, native ranges will yield photos with more complex image density patterns.

DRISCOLL, R. S., P. O. CURRIE, AND M. J. MORRIS.
1972.

Estimates of herbaceous standing crop by microdensitometry.

Photogramm. Eng. 38:591. (Abstr.)

Paper presented at 38th annual meeting of American Society of Photogrammetry, Washington, D. C., March 12-17, 1972.

DRISCOLL, R. S., AND M. M. SPENCER.*
1972.

Multispectral scanner data for plant community classification.

Eighth Int. Symp. Remote Sensing Environ. [Ann Arbor, Mich., Oct. 1972] Abstr. of Pap., p. 127-128.

Recognition processing was done on a general purpose digital computer and a special purpose analog recognition computer. Generalized plant communities were acceptably discriminated, but not all specific community types were classified as belonging to their appropriate grassland systems.

DRISCOLL, R. S., AND M. M. SPENCER.*
1972.

Multispectral scanner imagery for plant community classification.

Int. Symp. Remote Sensing Environ. [Ann Arbor, Mich., Oct. 1972] Proc. 8:1259-1278.

Intensive preprocessing of spectral data was required. Generalized plant community types--forest, grassland, and hydrophytic systems--were acceptably classified. Serious, but soluble, errors occurred when classifying specific communities within the grassland system. Special clustering analyses improved these classifications.

DRISCOLL, RICHARD S., AND RICHARD E. FRANCIS.
1973.

70mm aerial photographs for range vegetation analysis.

Soc. Range Manage. [Boise, Idaho, Feb. 1973] Abstr. of Pap. 26:13.

Sampling can (1) determine areal extent of intricate plant communities, (2) detect and identify individual shrubby and herbaceous species, (3) estimate relative amounts of plant cover and bare soil, (4) estimate herbaceous standing crop, and (5) estimate population dynamics of some small mammals in relation to habitat change.

DRISCOLL, RICHARD S., JACK N. REPPERT, AND ROBERT C. HELLER.*
1974.

Microdensitometry to identify plant communities and components on color infrared aerial photos.

J. Range Manage. 27:66-70.

Image density differences can be used to discriminate individual shrub and tree species of a pinyon pine-juniper plant community. Image density was also used to identify six general plant communities. Sites and cultural treatments within native grasslands and ponderosa pine forest could not be so easily discriminated.

DRISCOLL, RICHARD S., AND MERVIN D. COLEMAN.*
1974.

Color for shrubs.

Photogramm. Eng. 40:451-459.

Identification of individual shrubs was significantly better on large-scale (1:800-1:1,500) 70-mm color-infrared aerial photographs than on normal color. Photoscales smaller than 1:2,400 had limited value except for mature individuals of relatively tall species.

DRISCOLL, RICHARD S.
1974.

Use of remote sensing in range and forest management. Proc. Great Plains Agric. Counc. 1974:111-133.

Aerial photography of various kinds will continue to be the primary tool for remote sensing of vegetation for at least several years. Development of computerized optical-mechanical scanners looks promising, but human input is necessary in interpreting data. Usefulness of satellite imagery is uncertain.

DRISCOLL, RICHARD S., RICHARD E. FRANCIS, JAMES A. SMITH,* AND ROY A. MEAD.*
1974.

ERTS-1 data for classifying native plant communities--central Colorado.

Int. Symp. Remote Sensing Environ. [Ann Arbor, Mich., April 1974] Proc. 9:1195-1211.

Visual interpretation and machine processing of system-corrected ERTS-1 data provided similar results for classifying native plant communities to the Regional Level. Classification to the Series Level was not as successful.

DRISCOLL, RICHARD S., AND THOMAS C. WATSON.
1974.

Aerial photography for pocket gopher populations. p. 481-492. In Proc. Symp. Remote Sensing and Phot74.

Aerial photography for pocket gopher populations. p. 481-492. In Proc. Symp. Remote Sensing and Photo Interpretation [Banff, Alberta, Can., Oct. 1974] Int. Soc. Photogramm. Comm. VII, vol. 2, Can. Inst. Surveying, Ottawa, Ont.

Mounds of soil produced by burrowing pocket gophers, which are highly correlated with population density, were interpreted from color and color-infrared aerial photos. Population estimates from 1:600 scale color-infrared photos were 97 percent as accurate as estimates from ground evaluations.

DRISCOLL, RICHARD S., AND RICHARD E. FRANCIS.
1975.

Range inventory: Classification of plant communities.

p. 26-43. In Evaluation of ERTS-1 data for forest and rangeland surveys. USDA For. Serv. Res. Pap. PSW-112, 67 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Tests showed data gathered by the first Earth Resources Technology Satellite would be useful to managers of large forest ownerships. Forest and nonforest lands were distinguished with 90-95 percent accuracy. Forest disturbances could be detected with 90 percent accuracy when ERTS data were compared with aerial photos.

Land Use Alternatives

LEWIS, GORDON D.

1973.

Social influences on forest exploitation. Seventh World For. Congr. [B. Aires, Argent., Oct. 1972] Proc. Prepr. 7CFM/C:III/1E, 7 p.

Developing nations need to utilize forests to improve incomes and provide physical needs. As nations develop, however, demands for noneconomic products and services of the forests increase. Allocation of forest lands to production of specific products and benefits may meet present needs while providing for future use.

LEWIS, GORDON D.

1974.

Land use planning activities in the Forest Service. p. 16-21, In Impact of Land Use Planning Semin. Proc. Great Plains Agric. Counc. Publ. 69.

Resource management guides for Federal land management agencies now require more comprehensive land-use planning. Because the new process must identify, quantify, evaluate, and coordinate a complex combination of overlapping and independent ecological, social, and economic systems, planning must be done by an interdisciplinary team aided by public input.

LEWIS, GORDON D.

1975.

Major problems in rural development unique to the Great Plains: A panel. p. 108-112. In Rural development in the Great Plains: Problems and potentials. Great Plains Agric. Counc. Publ. 75, 140 p.

Development will result from increased recreation and mineral extraction. New concepts, regulations, and laws on land ownership, land use and reclamation, and water quality and quantity are required if we are to avoid extensive environmental damage. Social and economic considerations must be evaluated to guide land use planners.

O'CONNELL, PAUL F., AND RON S. BOSTER.

1974.

Demands on National Forests require coordinated planning. Ariz. Rev. 23(2):1-7.

Alternative uses and increasing resource scarcity require a change from basing allocation policies on simple physical characteristics of resources to the use of economic criteria. Production decisions must consider economic demand as well as supply. The Mogollon Rim study in Arizona illustrates use of economic values.

TURNER, JAMES M.

1974.

Allocation of forest management practices on public lands.

Ann. Reg. Sci. 8(2):72-88.

Describes a process for integrating product yields, costs, and values into a planning framework which broadly defines management practices on National Forest lands.

Resource Management Economics

BOSTER, RON S., PAUL F. O'CONNELL, AND JAMES C. THOMPSON.

1974.

Recreation uses change Mogollon Rim economy. Ariz. Rev. 23(8,9):1-7.

An economy based on cattle and wood has changed to one based on second homes, retirement living, and transient recreation.

Safeguards are inadequate to prevent environmental degradation associated with rapid population and economic growth. The problems and solutions are equally complex.

BROWN, THOMAS C., PAUL F. O'CONNELL, AND ALDEN R. HIBBERT.

1974.

Chaparral conversion potential in Arizona. Part II: An economic analysis.

USDA For. Serv. Res. Pap. RM-127, 28 p.

Some 139 chaparral areas totaling 332,796 acres meet crown cover, slope, and managerial criteria for conversion. Using fire for conversion, 96 areas have a benefit-cost ratio greater than 1; with soil-applied herbicide, 72 areas meet that economic criterion. Other resources should be favorably affected.

BROWN, THOMAS C.,* AND RON S. BOSTER.

1974.

Effects of chaparral-to-grass conversion on wildfire suppression costs.

USDA For. Serv. Res. Pap. RM-119, 11 p.

Properly planned, carried out, and maintained, chaparral-to-grass conversions should reduce the occurrence of large, expensive wildfires. Dollar values of 'fire benefits' were calculated for 141 convertible areas in Arizona's Salt-Verde Basin. Case histories of large chaparral fires are analyzed to illustrate principles of chaparral and grass fires in the Southwest. Historical fire data were used in a predictive model, but where data were absent or insufficient, parameters were varied within specified limits. The fire benefit, though not as high as water and forage benefits resulting from conversion, is an important addition to a benefit-cost analysis. The fire benefit varies significantly from area to area because of differences in man-caused and lightning risks, and also in accessibility. While transference of dollar values to other areas is tenuous, the methodology is transferable and can be a very useful planning tool.

COLBY, MARILYN K., AND GORDON D. LEWIS.

1973.

Economics of containerized conifer seedlings.

USDA For. Serv. Res. Pap. RM-108, 7 p.

Containerized seedlings, grown in a controlled environment greenhouse, can substantially reduce time required to produce high quality seedlings, and improve seedling survival rates in outplantings. Costs per thousand surviving trees are estimated to be \$460 for 2-0 bare-root stock, \$441 for 2-1 potted stock, \$393 for containerized greenhouse seedlings.

GARTNER, F. ROBERT,* AND KIETH E. SEVERSON.

1972.

Fee hunting in western South Dakota.

J. Range Manage. 25:234-237.

Big-game hunting fee system, now practiced by some landowners, could further cause for good range management while simultaneously maximizing economic return from rangeland.

LEWIS, GORDON D.

1975.

The benefits of vacation home developments to county governments.

p. 114-120. In Man, leisure, and wildlands: A complex interaction. [Proc. First Eisenhower Consortium Res. Symp., Sept. 14-19, 1975, Vail, Colo.] Eisenhower Consortium Bull. 1, 286 p.

At first, vacation home developments have relatively high benefit-cost ratios with respect to their requirements for government services, but these ratios can be reversed. County officials and land developers must provide early guidance to insure these developments are not detrimental to long-term county revenue-cost relationships.

MILLER, ROBERT L., AND FREDERIC R. LARSON.

1973.

A cost analysis of clearing a ponderosa pine watershed.

USDA For. Serv. Res. Note RM-231, 7 p.

After a commercial logging operation, cost of felling unmerchantable small trees and windrowing slash was \$72.09 per acre. Costs could probably be reduced 40 percent or more by changes in treatment prescription, choice of equipment, and removal of pulpwood and firewood where markets are available.

O'CONNELL, PAUL F.

1972.

Economics of chaparral management in the Southwest. p. 260-266. In Watersheds in Transition Symp. [Fort Collins, Colo., June 1972] Proc. Ser. 14, 405 p. Am. Water Resour. Assoc., Urbana, Ill.

A meaningful quantitative analysis can be made of a proposed chaparral management program. On the Tonto National Forest, for example, several million dollars would be spent on outdoor recreation facilities in water-oriented and ponderosa pine areas before chaparral areas could compete.

O'CONNELL, PAUL F., AND HARRY E. BROWN.

1972.

Use of production functions to evaluate multiple use treatments on forested watersheds.

Water Resour. Res. 8:1188-1198.

Product-product functions were developed for water, timber, and herbage for five strip cutting alternatives. They indicate the supplementary, complementary, and competitive outputs obtained from a given expenditure. Outputs and costs were evaluated over a 90-year period.

O'CONNELL, PAUL F.

1972.

Valuation of timber, forage and water from National Forest lands.

Ann. Reg. Sci. 6(2):1-14.

Because some forest products are not sold in the market place, it is difficult to fit their outputs into economic models. Multi-objective alternatives for identifying relative worth include economic efficiency, regional development, and environmental quality. Economic criteria are logical for timber, forage, and consumptive water.

O'CONNELL, PAUL F.

1974.

Detailed studies in the Salt-Verde watershed.

p. 52-57. In 18th Annu. Ariz. Watershed Symp. [Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm. Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-127, the status-of-our-knowledge publication by the Rocky Mountain Station. A copy of the Proceedings may be requested from the Arizona Water Commission, Phoenix.

SEVERSON, KIETH E., AND F. ROBERT GARTNER.*

1972.

Problems in commercial hunting systems: South Dakota and Texas compared.

J. Range Manage. 25:342-345.

Comparisons center around four factors: state hunting regulations, proximity of public lands, hunter demand and the game crop, and attitudes of landowners and hunters.

SUBLETTE, WERNER J.,* AND WILLIAM E. MARTIN.*

1975.

Outdoor recreation in the Salt-Verde Basin of central Arizona: Demand and value.

Ariz. Agric. Exp. Stn. Tech. Bull. 218, 41 p.

Higher net values and larger expenditures are associated with sites that have water-based recreation, considerable development at the sites, and fairly easy access. Single copy may be ordered from University of Arizona, Tucson.

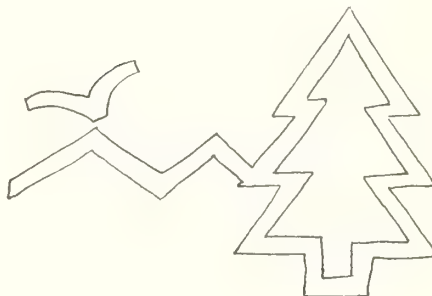
TURNER, JAMES M., AND FREDERIC R. LARSON.

1974.

Cost analysis of experimental treatments on ponderosa pine watersheds.

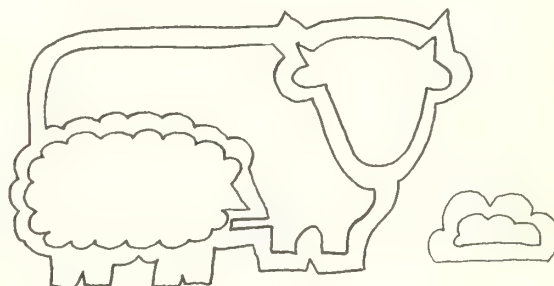
USDA For. Serv. Res. Pap. RM-116, 12 p.

A regression model predicts thinning and piling costs as a function of the degree of timber basal area removed. Thinning costs are related to basal area removed noncommercially, while piling costs are related to total basal area removals including commercial logging.



Volume?

CONDITION?



AVAILABILITY?

value?



WATERSHED MANAGEMENT

*Private, State or Federal cooperator

Geology

MARCUS, STEVEN R.

1973.

Geology of the Montane Zone of central Colorado--with emphasis on Manitou Park.

USDA For. Serv. Res. Pap. RM-113, 20 p.

Geologic features of four parts of the Montane Zone of central Colorado are described: (1) the Front Range, (2) the Sangre de Cristo Mountains, (3) the Spanish Peaks, and (4) the Wet Mountains. Detailed description and geologic map of the Manitou Experimental Forest are included, which provide some of the information useful in determining applicability of study results to other parts of the Zone.

Soils, Erosion

ALDON, EARL F., AND GEORGE GARCIA.

1973.

Seventeen-year sediment production from a semiarid watershed in the Southwest.

USDA For. Serv. Res. Note RM-248, 4 p.

Average annual rate of sediment production declined 71 percent in the period 1967-71 compared with the period 1956-66 on a 471-acre watershed on the Rio Puerco drainage in New Mexico. This decline was a result of an increase in plant size and litter production on the alluvial flood plain.

BOSTER, RON S., AND LESTER R. DAVIS.

1972.

Soil-loss considerations in chaparral-to-grass conversions.

p. 243-250. *In Watersheds in Transition Symp.* [Fort Collins, Colo., June 1972] Proc. Ser. 14, 405 p. Am. Water Resour. Assoc., Urbana, Ill.

Chaparral conversions can be designed with minimal initial sediment loss; vegetative conversions can save soil over time. Properly planned conversions would cause negligible to nonexistent off-site sediment impacts.

HEEDE, BURCHARD H.

1974.

Stages of development of gullies in Western United States of America.

Z. Geomorphol. 18(3):260-271.

Gully development should be recognized in terms of land form evolution. Comparison of hydraulic geometry of gullies with that of rivers suggests that the mature stage should be characterized by dynamic equilibrium. In ephemeral gullies, channel vegetation may also indicate stability.

HEEDE, BURCHARD H.

1975.

Mountain watersheds and dynamic equilibrium.

Watershed Manage. Symp., ASCE Irrig. Drain. Div. [Logan, Utah, Aug. 1975] Proc. 1975:407-420.

If considered in short timespans, landform processes may be 'dormant' between periods of change. This state of balance, called dynamic equilibrium, between landform and aggressive forces may be upset by unusual natural events, or by man's activities. Treatment effects should be considered from this viewpoint.

HEEDE, BURCHARD H.

1975.

Stages of development of gullies in the West.

p. 155-161. *In Present and prospective technology for predicting sediment yields and sources.* U.S. Dep. Agric., Agric. Res. Serv. ARS-S-40, 285 p. (Proc. Sediment-Yield Workshop, Oxford, Miss., Nov. 1972.)

Gully development should be recognized in terms of land form evolution. Comparison of hydraulic geometry of gullies with that of rivers suggests that the mature stage should be characterized by dynamic equilibrium. In ephemeral gullies, channel vegetation may also indicate stability.

HEEDE, BURCHARD H.

1975.

Watershed indicators of landform development.

p. 43-46. *In Vol. 5, Hydrol. Water Resour. in Ariz. and the Southwest. Proc. 1975 Meet. Ariz. Sect., Am. Water Resour. Assoc. and Hydrol. Sect., Ariz. Acad. Sci., [Tempe, Ariz., Apr. 1975.]*

Examples show that factors in the hydraulic geometry of streams indicate whether a watershed is in an active stage of landform development, or is in dynamic equilibrium. If geomorphology is not considered, research results could be misinterpreted.

INGEBO, PAUL A., AND ALDEN R. HIBBERT.

1974.

Runoff and erosion after brush suppression on the Natural Drainage watersheds in central Arizona.

USDA For. Serv. Res. Note RM-275, 7 p.

Herbicide treatment of sparse chaparral cover on two small catchments in central Arizona caused annual streamflow to increase 22 percent (0.36 inch) on the average. Grasses and forbs also increased, while the amount of sediment trapped at the gaging station declined.

LEAF, CHARLES F.

1974.

A model for predicting erosion and sediment yield from secondary forest road construction.

USDA For. Serv. Res. Note RM-274, 4 p.

One of the more visible and controversial environmental impacts associated with timber harvesting and development in central Colorado is road construction. This Note summarizes available data, and from this base, proposes a preliminary model for predicting an index of onsite erosion and downstream sediment yield.

STURGES, DAVID L.

1975.

Sediment transport from big sagebrush watersheds. Watershed Manage. Symp., ASCE Irrig. Drain. Div. [Logan, Utah, Aug. 1975] Proc. 1975:728-738.

Suspended sediment and bedload transport were low on two small Wyoming watersheds. The majority of sediment movement occurred during snowmelt runoff. Movement was especially high during unique oversnow runoff events.

YAMAMOTO, TERUO, AND HENRY W. ANDERSON.*

1973.

Splash erosion related to soil erodibility and other forest soil properties in Hawaii.

Water Resour. Res. 9:336-345.

Erodibility index and bulk density jointly with saturation moisture content accounted for the highest proportion of gross splash erosion variation; organic matter content and erodibility index accounted for the highest proportion of variation in

Rehabilitation, Erosion Control

ALDON, EARL F.

1972.

Meander protection for stabilizing vertical gully walls.
Am. Geophys. Union Trans. 53:977. (Abstr.)

Meander undercutting and subsequent sloughing of walls enlarge gullies and increase sediment loads. Describes the design of low-cost meander protection structures used on a large gully in New Mexico.

ALDON, EARL F.

1972.

Reactivating soil ripping treatments for runoff and erosion control in the Southwestern US.

Ann. Arid Zone 11:154-160.

Opening old rips sealed over with sediment was as effective in controlling runoff as ripping between old rips. Re-ripping by either method reduced runoff by two-thirds. Ripping must be done carefully to avoid subterranean channel formation.

ALDON, EARL F.

1976.

Soil ripping treatments for runoff and erosion control.
Fed. Inter-Agency Sediment. Conf. [Denver, Colo., Mar. 1976] Proc. 3:2-24--2-29.

Soil ripping, a form of deep, wide plowing, effectively reduces runoff and erosion from semiarid watersheds. Surface runoff was still reduced 85 percent and erosion 31 percent 3 years after treatment. Treatment effectiveness declined after 3 to 5 years depending on amounts and intensities of summer thunderstorms.

HEEDE, BURCHARD H., AND JOHN G. MUFICH.

1973.

Functional relationships and a computer program for structural gully control.

J. Environ. Manage. 1:321-344.

Relations are presented between effective dam height and volume of material, cost, spacing, number of dams required, expected sediment deposits, and sediment value-treatment cost ratio. Phase I computer programs yield different design choices; Phase II selects final individual dam design and overall treatment. Programs are operational.

HEEDE, BURCHARD H., AND JOHN G. MUFICH.

1974.

Field and computer procedures for gully control by check dams.

J. Environ. Manage. 2:1-49.

Computerized design of gully control by check dams eases field survey and design procedures. A minimum of data is required to design gully treatments and yield cost information. Graphical computer output shows relationships between choices by effective dam height, total cost of treatment, and benefits from expected sediment deposits.

HEEDE, BURCHARD H.

1975.

Submerged burlap strips aided rehabilitation of disturbed semiarid sites in Colorado and New Mexico.
USDA For. Serv. Res. Note RM-302, 8 p.

Two planting sites with narrow submerged burlap strips showed 14 times less soil loss than control sites without burlap. Gullies and deep rills need to be reshaped to gentle swales before burlap is installed. Plant cover should become established before burlap disintegrates--in about 5 years.

Hydrology—Western Forest and Alpine Types

BROWN, HARRY E., MALCHUS B. BAKER, JR., JAMES L. ROGERS, WARREN P. CLARY, J. L. KOVNER, FREDERIC R. LARSON, CHARLES C. AVERY, AND RALPH E. CAMPBELL.

1974.

Opportunities for increasing water yields and other multiple use values on ponderosa pine forest lands.

USDA For. Serv. Res. Pap. RM-129, 36 p.

Multiple use productivity is described, with special emphasis on the Beaver Creek Pilot Watershed near Flagstaff, Arizona. Changes in productivity and environmental quality are described following livestock grazing and various levels of forest thinning and clearing. Preliminary analytical procedures allow the user to estimate the tradeoffs in production and environmental quality.

CLARY, WARREN P., MALCHUS B. BAKER, JR., PAUL F. O'CONNELL, THOMAS N. JOHNSEN, JR.,* AND RALPH E. CAMPBELL.

1974.

Effects of pinyon-juniper removal on natural resource products and uses in Arizona.

USDA For. Serv. Res. Pap. RM-128, 28 p.

Describes results of pilot treatments to increase yields of water and forage by removing pinyon and juniper trees. Herbicide treatments are more effective than mechanical removal of trees, but even on the more successful projects, costs and benefits are about even. Effects on other resources are about neutral.

FRANK, ERNEST C.

1973.

Snow amount in relation to streamflow and herbage production in western Colorado.

J. Range Manage. 26:32-34.

A 10 percent increase in peak snowpack, due to cloud seeding or natural events, is partly returned as runoff but has little, if any, immediate effect on the productivity and use of mountain grasslands.

FRANK, ERNEST C., HARRY E. BROWN, AND J. R. THOMPSON.

1975.

Hydrology of Black Mesa watersheds, western Colorado.

USDA For. Serv. Gen. Tech. Rep. RM-13, 11 p.

Eleven years of runoff and suspended sediment data show no relationship to bare soil intercept, which decreased although grazing utilized an average of 40 percent of the grass. By current classification schemes, sediment yields indicate very minor amounts of geologic erosion.

GARY, HOWARD L.

1972.

Rime contributes to water balance in high-elevation aspen forests.

J. For. 70:93-97.

The water contribution from rime for each of two winters studied was about 1 inch.

GARY, HOWARD L.

1974.

Growth of Engelmann spruce (*Picea engelmannii*) unaffected by increased snowpack.

Arct. and Alp. Res. 6:29-36.

Comparison of radial growth of spruce trees in forest interior (shallow snowpack) and near the edge of a burn (deep snowpack) suggest that weather modification to increase snowfall in the Southwest will have little detrimental effect on annual or long-term tree growth.

GARY, HOWARD L.

1974.

Snow accumulation and snowmelt as influenced by a small clearing in a lodgepole pine forest.

Water Resour. Res. 10:348-353.

The clearing affected the distribution of snow over the area but not the total snow water equivalent. Melt rates in the clearing were about twice those in the interior forest. Near the middle of the melt season the clearing contained 12 percent less snow water equivalent than the forest.

GARY, HOWARD L.
1974.

Snow accumulation and melt along borders of a strip cut in New Mexico.

USDA For. Serv. Res. Note RM-279, 8 p.

Snowfall amounts were similar along the sunny and shady borders of an east-west clearcut strip, but greater than in the adjacent forest. Snow disappeared 5 to 6 weeks earlier along the sunny border than along the shady border or forest interior.

GARY, HOWARD L.
1975.

Watershed management problems and opportunities for the Colorado Front Range ponderosa pine zone: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-139, 32 p.

Soils in the region were developed from granites, are relatively infertile, and erode easily after abuse. Water yields are relatively low. Plot studies corroborated with large-scale studies on timbered and grazed areas have provided guidelines for maintaining satisfactory watershed conditions.

HAEFFNER, ARDEN D., AND CHARLES F. LEAF.
1973.

Areal snow cover observations in the central Rockies, Colorado.

USDA For. Serv. Gen. Tech. Rep. RM-5, 15 p.

Photographic records of areal snow cover depletion during the 1964-71 snowmelt seasons in the Fraser Experimental Forest, and in the Park Range from 1966-71, are summarized. Included are detailed estimates of snow cover extent on more than 90 hydrologic subunits which comprise the six watersheds photographed. Applications of these data in streamflow forecasting, water balance analyses, and snow cover duration are suggested.

HEEDE, BURCHARD H.
1972.

Influences of a forest on the hydraulic geometry of two mountain streams.

Water Resour. Bull. 8:523-530.

Steps provided by logs fallen across the channel added to flow energy reduction. Implications for forest management are that sanitation cuts would not be permissible where a stream is in dynamic equilibrium and bed material movement should be minimized.

HEEDE, BURCHARD H.
1972.

Flow and channel characteristics of two high mountain streams.

USDA For. Serv. Res. Pap. RM-96, 12 p.

Logs fallen across the channels provided steps, adding to flow energy reduction. The streams required additional gravel bars to adjust to slope. More bars formed when fewer numbers of logs were available. The streams had attained dynamic equilibrium. Removal of dead and dying trees (sanitation cutting) would not be permissible where such equilibrium exists and bed material movement should be minimized.

HOOVER, MARVIN D.
1975.

Watershed management in lodgepole pine ecosystems. p. 569-580. In Manage. Lodgepole Pine Ecosyst. Symp. [Pullman, Wash., Oct. 1973] Proc., 2 vols. David M. Baumgartner, ed. Wash. State Univ., Pullman.

The proportion of water yield to precipitation is high because of cold climate, short growing season, and accumulation of an overwinter snowpack. Water quality is excellent but subject to damage by road construction. Yields can be increased, but the larger amounts flow off during the natural high-water season.

LEAF, CHARLES F., AND JACOB L. KOVNER.
1972.

Sampling requirements for areal water equivalent estimates in forested subalpine watersheds.

Water Resour. Res. 8:713-716.

Guidelines developed for sampling mountain snowpacks on an areal basis were: (1) sampling zones should be stratified by elevation, the sampling in each zone being proportional, and (2) sampling points should be widely spaced over each zone, two duplicate measurements at most being made at a location.

LEAF, CHARLES F., AND GLEN E. BRINK.
1972.

Simulating effects of harvest cutting on snowmelt in Colorado subalpine forest.

p. 191-196. In Watersheds in Transition Symp. [Fort Collins, Colo., June 1972] Proc. Ser. 14, 405 p. Am. Water Resour. Assoc., Urbana, Ill.

Results from the model agree in general with empirical knowledge, which indicates the model can be developed into a useful tool for simulating alternatives to help determine which harvest cutting systems will optimize patterns of snowmelt.

LEAF, CHARLES F., AND GLEN E. BRINK.
1972.

Simulating watershed management practices in Colorado subalpine forest.

ASCE Annu. Natl. Environ. Eng. Meet. [Houston, Tex., Oct. 1972] Prepr. 1840, 26 p.

A dynamic model is being developed for simulating the hydrologic behavior of subalpine watersheds. Preliminary results show the probable directions and magnitudes of hydrologic changes resulting from timber harvesting and weather modification.

LEAF, CHARLES F., AND GLEN E. BRINK.
1972.

Annual streamflow summaries from four subalpine watersheds in Colorado.

USDA For. Serv. Gen. Tech. Rep. RM-1, 24 p.

Streamflow runoff summaries are presented for four experimental watersheds near Fraser and Steamboat Springs, Colorado. Interval of published record varies from 1943-71 at Fraser to 1967-71 at Steamboat Springs.

LEAF, CHARLES F., AND GLEN E. BRINK.
1973.

Computer simulation of snowmelt within a Colorado subalpine watershed.

USDA For. Serv. Res. Pap. RM-99, 22 p.

A dynamic model simulates snowmelt for all combinations of aspect, slope, elevation, and forest cover composition and density. The model simulates winter snow accumulation, energy balance, snowpack condition, and resultant melt.

LEAF, CHARLES F., AND GLEN E. BRINK.
1973.

Hydrologic simulation model of Colorado subalpine forest.

USDA For. Serv. Res. Pap. RM-107, 23 p.

Designed to determine probable hydrologic changes resulting from watershed management, the model simulates total water balance on a year-round basis and compiles results from individual hydrologic response units into a 'composite overview' of an entire basin. Results are summarized for an 8-year period on a 667-acre experimental watershed.

LEAF, CHARLES F.
1974.

More water from mountain watersheds.

Colo. Rancher Farmer 28(7):11-12.

A feature article that tells how carefully designed patch cutting in lodgepole pine and spruce-fir forests can increase water yields.

LEAF, CHARLES F., AND GLEN E. BRINK.

1975.

Land use simulation model of the subalpine coniferous forest zone.

USDA For. Serv. Res. Pap. RM-135, 42 p.

A dynamic model simulates the short- and long-term hydrologic impacts of combinations of timber harvesting and weather modification to develop management strategies for planning intervals which can vary from a few years to the rotation age of subalpine forests (120 years and longer).

LEAF, CHARLES F.

1975.

Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-137, 31 p.

Reviews field studies on the effects of watershed management practices on snow accumulation, melt, and subsequent runoff, and simulation models to predict the hydrologic impacts of timber harvesting and weather modification. Highlights research needs, and summarizes guidelines for implementing watershed management principles in land use planning.

LEAF, CHARLES F.

1975.

Watershed management in the central and southern Rocky Mountains: A summary of the status of our knowledge by vegetation types.

USDA For. Serv. Res. Pap. RM-142, 28 p.

Summarizes a series of comprehensive reports on watershed management in five major vegetation zones: (1) the coniferous forest subalpine zone; (2) the Front Range ponderosa pine zone; (3) the Black Hills ponderosa pine zone; (4) the alpine zone; and (5) the big sagebrush zone. Includes what is known about the hydrology of these lands, what hydrologic principles are important for multiresource management, and what additional information is needed for each vegetation type. (Available from Superintendent of Documents, Stock No. GPO 001-001-00398.)

MARTINELLI, M., JR.

1975.

Water-yield improvement from alpine areas: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-138, 16 p.

Snowpack management can be an effective means of improving water yields from the already productive alpine type. Snow accumulates in the lee of terrain breaks, and fences upwind of natural accumulation areas effectively trap additional snow. Snowfences can also control blowing and drifting snow on highways and in avalanche-prone areas.

ORR, HOWARD K.

1972.

Throughfall and stemflow relationships in second-growth ponderosa pine in the Black Hills.

USDA For. Serv. Res. Note RM-210, 7 p.

Rainfall alone accounted for 85 to 99 percent of throughfall variation. Stemflow was also primarily dependent on rainfall. Results further demonstrate adjustment of throughfall for mean canopy density, adjustment of stemflow for tree d.b.h., and combination of these relationships to estimate net rainfall for different stand densities.

ORR, HOWARD K., AND TONY VANDER HEIDE.*

1973.

Water yield characteristics of three small watersheds in the Black Hills of South Dakota.

USDA For. Serv. Res. Pap. RM-100, 8 p.

Three small forested watersheds in the northeastern Black Hills have yielded surface runoff equivalent to 25, 27, and 23 percent of average annual precipitation, water years 1964-69, inclusive. Net differences between precipitation and outflow closely approximate yearly evapotranspiration.

ORR, HOWARD K.

1973.

The Black Hills (South Dakota) flood of June 1972: Impacts and implications.

USDA For. Serv. Gen. Tech. Rep. RM-2, 12 p.

Rains of 12 inches or more fell in 6 hours; resulting flash floods exacted a disastrous toll in human life and property. Rainfall and discharge were so great that recurrence intervals are presented in multiples of the estimated 50- or 100-year event. Quick runoff was produced regardless of hydrologic condition.

ORR, HOWARD K.

1975.

Watershed management in the Black Hills: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-141, 12 p.

Climate, geology, soils, vegetation, and water yields are briefly described, followed by a review and discussion of watershed management research and problems unique to the Black Hills. Research needs with respect to water quality, data collection, and model development are highlighted.

RICH, LOWELL R.

1972.

Managing a ponderosa pine forest to increase water yield.

Water Resour. Res. 8:422-428.

An improved type of timber harvest and subsequent management were applied to determine how it influenced water and sediment yields, wildlife, and scenic values as well as the long-term effect on timber. Water yields improved significantly, with no measurable sediment trapped above the weir.

RICH, LOWELL R., AND J. R. THOMPSON.

1974.

Watershed management in Arizona's mixed conifer forests: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-130, 15 p.

Removing mixed conifer forest vegetation has increased water yields approximately in proportion to the percent of the area in cleared openings. When fitted to the timber-stand structure, patchcutting is compatible with recommended mixed conifer silviculture, beneficial to wildlife, and esthetically pleasing.

SOLOMON, RHEY M.,* PETER F. FFOLIOTT,* MALCHUS B. BAKER, JR., GERALD J. GOTTFRIED, AND J. R. THOMPSON.

1975.

Snowmelt runoff efficiencies on Arizona watersheds.

Ariz. Agric. Exp. Stn. Res. Rep. 274, 50 p.

Documents efficiencies for several experimental watersheds in different vegetation zones. Tentative regression equations were developed relating snowpack runoff efficiencies to inventory-prediction variables. Timing of precipitation during the accumulation-melt period is of prime significance.

THOMPSON, J. R.

1974.

Energy budget measurements over three cover types in eastern Arizona.

Water Resour. Res. 10:1045-1048.

Energy budget measurements were used to determine seasonal patterns of the ratio of evapotranspiration (ET) to net radiation (Rn).

THOMPSON, J. R.

1974.

Water yield research in Arizona's mixed conifer forests.

p. 15-17. In 18th Annu. Ariz. Watershed Symp. [Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm. Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-130, the status-of-our-knowledge publication by the Rocky Mountain Station. A copy of the Proceedings may be requested from the Arizona Water Commission, Phoenix.

THOMPSON, J. ROBERT.

1975.

Energy budgets for three small plots--substantiation of Priestley and Taylor's large-scale evaporation parameter.

J. Appl. Meteorol. 14(7):1399-1401.

Energy balance data collected in the White Mountains of Arizona indicate the variability in alpha for unsaturated conditions, and seem to verify a constant value of 1.26 for saturated conditions. The 'index of aridity' ($\alpha/1.26$), though not entirely logical for small-scale use, also seems to substantiate the large-scale parameter.

YAMAMOTO, TERUO, AND HOWARD K. ORR.

1972.

Morphometry of three small watersheds, Black Hills, South Dakota, and some hydrologic implications.

USDA For. Serv. Res. Pap. RM-93, 15 p.

Morphometry and hydrologic character are analyzed in terms of elementary length dimensions, nondimensional expressions, and similitude concepts. It is theorized that these form elements (1) exert primary control over volume yield and peak flows, and (2) are better indicators of relative volume yields and peak flows than is surface area.

Hydrology—Shrub and Grass Types

HIBBERT, ALDEN R., EDWIN A. DAVIS, AND DAVID G. SCHOLL.

1974.

Chaparral conversion potential in Arizona. Part I: Water yield response and effects on other resources.

USDA For. Serv. Res. Pap. RM-126, 36 p.

On favorable areas, conversion to grass reduces fire hazard and increases water yield and forage for livestock. If treatment areas are small, the edge effect created will enhance the environment for wildlife. Control methods effective in Arizona are rootplowing, prescribed burning, chemicals, and chemicals in combination with the others.

HIBBERT, ALDEN R.

1976.

Percolation and streamflow in range and forest lands. p. 61-72. In Watershed management on range and forest lands. Proc. Fifth Workshop of U.S./Aust. Rangelands Panel, Boise, Idaho, June 1975.

Differences in surface and subsurface hydrology on range and forest lands stem largely from differences in climate, soils, vegetation, and topography. Infiltration, or lack of it, is a critical process in the hydrology of these lands, especially as related to flooding characteristics.

INGEBO, PAUL A.

1972.

Converting chaparral to grass to increase streamflow. p. 181-192. In Hydrology and water resources in Arizona and the Southwest. Ariz. Sect., Am. Water Resour. Assoc., and Hydrol. Sect., Ariz. Acad. Sci. [Prescott, Ariz., May 1972] Proc. v. 2, 492 p.

Chemical treatment of one of a pair of calibrated watersheds increased average annual runoff 0.61 inch. Pelleted funuron was applied to 15 percent of the area along stream channels. Streamflow was intermittent before treatment in 1967, but has been continuous since.

PASE, CHARLES P.

1972.

Litter production from oak-mountainmahogany chaparral in central Arizona.

USDA For. Serv. Res. Note RM-214, 7 p.

Annual litter fall of shrub live oak was 192 g/sq m crown area on southerly slopes, and 138 g on northerly slopes. For the chaparral community as a whole, southerly aspects produced 193 g/sq m crown areas and northerly aspects, 215 g. Most litter fell during late spring and early summer, least in fall and early winter. Forest floor varied from 9.2 to 27.1 metric tons per ha. Maximum water retained against free drainage was 4.8 mm under shrub live oak and 5.1 mm under Pringle manzanita.

STURGES, DAVID L.

1973.

Soil moisture response to spraying big sagebrush the year of treatment.

J. Range Manage. 26:444-447.

Spraying with 2,4-D in Wyoming reduced soil moisture loss 24 percent between June 24, the treatment date, and September 30. All of the reduction accrued by August 4, during active growth; 83 percent of the reduction was in soil 2 to 6 ft deep.

STURGES, DAVID L.

1975.

Hydrologic relations on undisturbed and converted big sagebrush lands: The status of our knowledge.

USDA For. Serv. Res. Pap. RM-140, 23 p.

Climate, soils, vegetation, snow accumulation, and water yields are described, followed by a review of how management practices alter vegetative composition and the hydrologic regime. Potential hydrologic benefits from managing blowing snow in the big sagebrush type are outlined and research needs are highlighted.

STURGES, DAVID L.

1975.

Oversnow runoff events affect streamflow and water quality.

p. 105-117. In Snow Manage. on Great Plains Symp. [Bismarck, N. Dak., July 1975] Proc. Great Plains Agric. Coun. Publ. 73, 186 p.

Oversnow flow, which develops when snow melts rapidly early in the melt season, increases maximum flow rates three to five times, and runoff as a percentage of winter precipitation four times. Suspended sediment concentrations are also much higher.

Hydrology—Riparian and Phreatophyte Types

HORTON, JEROME S.

1973.

Evapotranspiration and water research as related to riparian and phreatophyte management: An abstract bibliography.

U.S. Dep. Agric. Misc. Publ. 1234, 192 p.

Over 700 entries are indexed and cross referenced. Purpose of abstract bibliography is to bring together published information that will help land managers and research workers to (1) evaluate relations of revegetation to water loss, and (2) estimate probable effect on water yield of manipulating vegetation.

HORTON, JEROME S., AND C. J. CAMPBELL.

1974.

Management of phreatophyte and riparian vegetation for maximum multiple use values.

USDA For. Serv. Res. Pap. RM-117, 23 p.

Summarizes the status of our knowledge about environmental relations of vegetation along water courses in the southwestern United States, and impacts of vegetation management to reduce evapotranspiration on other resource values. Suggests approaches to management of moist-site areas by zones based primarily on water table depth, elevation, and tree species.

Water Quality

DAVIS, E. A., AND P. A. INGEBO.

1973.

Picloram movement from a chaparral watershed.

Water Resour. Res. 9:1304-1313.

An estimated 4.5 percent of picloram, soil-applied as pellets in a brush-control treatment, was lost to stream water. Maximum concentrations, 370 parts per billion, were measured after heavy rainfall. Picloram was no longer detected after 14 months and 40 inches accumulated rainfall.

PATTON, DAVID R.

1973.

A literature review of timber-harvesting effects on stream temperatures: Research needs for the Southwest.

USDA For. Serv. Res. Note RM-249, 4 p.

Water temperature affects fish by changing their metabolic rate, changing oxygen content of water, influencing hatching and development time, and influencing migration. Creating a more open forest in the water-producing zone can change water temperature in shallow, low-volume streams. Research is needed on how timber harvesting affects water temperature to produce guidelines to meet Federal Water Pollution Control standards for cold-water fish.

Avalanches, Snow Physics

JUDSON, ARTHUR, AND BERNARD J. ERICKSON.

1973.

Predicting avalanche intensity from weather data: A statistical analysis.

USDA For. Serv. Res. Pap. RM-112, 12 p.

A two-parameter storm index and a discriminant function model predict the likelihood of avalanches in Colorado's Front Range. The storm index utilizes precipitation intensity modified by windspeed. The discriminant function model uses maximum 3-hour precipitation intensities, windspeed resolved to an optimum direction, and negative temperature departures from 20 degrees F.

JUDSON, ARTHUR.

1975.

Avalanche warnings: Content and dissemination.

USDA For. Serv. Res. Note RM-291, 8 p.

Snow avalanche warnings alert the public to unusually dangerous avalanche conditions. An effective warning message conveys a sense of urgency, and should have an official and authoritative source. Warnings are transmitted through the National Weather Service's communications network to the media and public.

MARTINELLI, M., JR.

1972.

Simulated sonic boom as an avalanche trigger.

USDA For. Serv. Res. Note RM-224, 7 p.

A linear array of detonating cord was used to simulate a sonic boom. The boom from such charges was directed toward the fracture zone of a small avalanche path where the snow was unstable, as indicated by natural avalanches in the area. On three of four tests, avalanches were released by a boom of 12 pounds per square foot (60 kg f/sq. m.) overpressure after withstanding lesser booms. One of the avalanches had a fracture face 8 feet 11 inches (272 cm) deep.

MARTINELLI, M., JR.

1973.

Avalanche.

p. 115-117, In Yearbook of Science and Technology, 1972. 468 p. McGraw-Hill, N.Y.

Recent avalanche research has focused on mechanical properties of snow on the ground, and how it fails just prior to an avalanche. Snow, weather, and avalanche history data are now used to determine when to use artillery to 'shoot down' avalanches along highways.

MARTINELLI, M., JR.

1974.

Snow avalanche sites: Their identification and evaluation.

U. S. Dep. Agric. Agric. Inf. Bull. 360, 27 p.

Avalanches in mountain areas threaten lives and damage property. Persons who plan to build new facilities or expand or relocate old ones should know how to recognize potentially dangerous sites. This bulletin describes and illustrates avalanche-prone areas and recommends a checklist to help evaluate field evidence of avalanche activity. (Available from Superintendent of Documents, Stock No. GPO 0100-03303, 75 cents.)

PERLA, R. I.

1972.

Generalization of Haefeli's creep-angle analysis.

J. Glaciol. 11:447-450.

A generalization of the creep angle, called the deformation-rate coefficient, is derived by replacing geometrical arguments with continuum mechanics. Once the coefficient is found from *in situ* measurements, the stress field of the slab can be determined from a set of hyperbolic partial differential equations.

PERLA, R. I.

1973.

Hyperbolic stress equations for compressible slabs.

Int. J. Non-Linear Mech. 8:253-259.

A constitutive law, chosen to model isotropic compressible slabs, is specialized for plane deformation and then substituted into the equations of motion. The resulting system is quasi-linear hyperbolic.

PERLA, R. I. (COMPILER).

1973.

Advances in North American avalanche technology: 1972 symposium.

USDA For. Serv. Gen. Tech. Rep. RM-3, 54 p.

Seven technical presentations, made in connection with the USDA Forest Service National Avalanche Training Program, discuss acoustic signals emitted by snow under stress, aspects of snow slab mechanics, use of explosives, and problems of avalanche dynamics.

SOMMERFELD, R. A.

1973.

Statistical problems in snow mechanics.

p. 29-36, In Advances in North American avalanche technology: 1972 symposium. USDA For. Serv. Gen. Tech. Rep. RM-3, 54 p.

For density measurements, the mean and standard deviation are meaningful parameters. For strength data, the mean is not very useful; extreme-value statistics should be used. Weibull statistics appear appropriate for evaluating tensile strength data, thread bundle statistics of Daniels for shear strength.

SOMMERFELD, RICHARD A.

1973.

The bulk tensile strength of snow.

Am. Geophys. Union Trans. 54:460. (Abstr.)

Tensile strengths of various snow types, from newly fallen to highly metamorphosed, were extrapolated to large volumes by fitting to Weibull distributions. These large-volume strengths were functions of both snow density and type.

SOMMERFELD, R. A.

1974.

A Weibull prediction of the tensile strength-volume relationship of snow.

J. Geophys. Res. 79:3353-3356.

A comparison of previous work and data presented here show

that the brittle tensile strength of snow varies with sample volume. If the hypothesis that snow has a predictable minimum tensile strength and that volumes larger than 1 cubic meter exhibit the minimum strength could be verified, predictions of slab failure might be greatly simplified.

SOMMERFELD, R. A.

1975.

Continuous measurements of deformations on an avalanche slope.

p. 293-297. *In* **Snow mechanics--Symposium [Grindelwald, Switz., Apr. 1974] IAHS-AISH Publ. 114.**

Deformation measurements are necessary to test methods of calculating stresses in snow slabs. The instruments described can be embedded in the slab and continuously monitor the positions of points in the slab without disturbance.

U.S. DEPARTMENT OF AGRICULTURE. FOREST SERVICE.

1975.

Avalanche protection in Switzerland. [Lawinenschutz in der Schweiz, translated by U.S. Army, CRREL]. USDA For. Serv. Gen. Tech. Rep. RM-9, 168 p.

This translation of a collection of 16 articles by Swiss avalanche experts summarizes the current state-of-the-art of structural control of avalanches in Europe. It includes chapters on avalanche formation and damage, supporting structures, deflecting and retarding structures, and political aspects of controls.

WILLIAMS, KNOX.

1972.

Avalanches in our western mountains: What are we doing about them.

Weatherwise 25:220-227.

Describes some tragic avalanches in the Cascades, then covers special weather forecasts and avalanche warnings, the National Avalanche School, protective structures and avalanche control, and avalanche zoning.

WILLIAMS, KNOX.

1975.

The snowy torrents: Avalanche accidents in the United States 1967-71.

USDA For. Serv. Gen. Tech. Rep. RM-8, 190 p.

This compilation of 76 avalanche accident reports teaches by example, both good and bad. Commentaries will help those who spend time in the mountains in winter how to avoid getting caught in an avalanche, or if caught, how to survive. (Available from Superintendent of Documents, Stock No. GPO 001-000-00399.)

WILLIAMS, KNOX.

1975.

Avalanche fatalities in the United States, 1950-75.

USDA For. Serv. Res. Note RM-300, 4 p.

Snow avalanches have caused 147 deaths over the last 25 years--an average of 6 per year. In the last 5 years, however, the death rate has doubled. Nearly three-fourths of all avalanche victims are recreationists.

Snow Fences, Blowing Snow

GARY, HOWARD L.

1975.

Airflow patterns and snow accumulation in a forest clearing.

West. Snow Conf. [Coronado, Calif., Apr. 1975] Proc. 43:106-113.

Comparisons before and after clearing a narrow opening in a lodgepole pine forest suggest that clearings may become saturated similar to snowfence systems, and that the accumulation pattern reflects primarily wind drift of falling snow rather than subsequent erosion and redeposition.

MARTINELLI, M., JR.

1973.

Snow-fence experiments in alpine areas.

J. Glaciol. 12:291-303.

Fences most successfully augmented natural snow accumulation at sites with level or gently sloping terrain downwind. Between 15 and 30 meters of 3-meter-tall fence was needed to produce an extra 1000 cubic meters of water equivalent in the snowfields at the beginning of the melt season.

MARTINELLI, M., JR.

1973.

Snow fences for influencing snow accumulation.

p. 1394-1398. *In* **The role of snow and ice in hydrology. Symp. on Measurement and Forecasting (WMO) [Banff, Alberta, Can., Sept. 1972] Proc. 2 vols.**

Efficiency of collecting snow fences is affected by height, density, and length of fence, bottom gap, length and maximum depth of lee drift, cumulative effect of tandem fences, tilting, terrain, and contributing distance.

SCHMIDT, R. A., JR.

1972.

Sublimation of wind transported snow--a model.

USDA For. Serv. Res. Pap. RM-90, 24 p.

Sublimation from blowing snow is estimated from the balance of heat and mass transfer on a volume of air and nonuniform ice particles. Size and the distribution of sizes are important particle factors, but fragmented and abraded shapes appear to increase sublimation only slightly above the estimate for spherical particles. Humidity and temperature are the overriding environmental factors, but atmospheric pressure and solar radiation are also important. The effect of turbulence on convection around the particles does not appear important in view of the small particle sizes encountered. Rather, turbulent transfer determines the snow concentration profile, and the gradients of heat and water vapor necessary to balance the sublimation process.

TABLER, RONALD D.

1973.

Snow fences improve highway safety.

Pub. Works 104(8):74-75.

Fence design is based on the distance a blowing snow particle can travel before it sublimates. Carefully located 12-foot-tall fences keep drifts off Interstate 80, and improve visibility.

TABLER, RONALD D.

1973.

New snow fence design controls drifts, improves visibility, reduces road ice.

Annu. Transp. Eng. Conf. [Denver, Colo., Feb. 1973] Proc. 46:16-27.

Research results were used to determine best height, spacing, and location of fences in an extensive snow fence system on Interstate 80 in southeastern Wyoming. In addition to exceptionally effective drift control, ice formation was reduced and visibility improved dramatically.

TABLER, RONALD D.

1973.

Evaporation losses of windblown snow, and the potential for recovery.

West. Snow Conf. [Grand Junction, Colo., Apr. 1973] Proc. 41:75-79.

Losses are defined in terms of transport distance, the average distance a snow particle must travel before completely evaporating. Extensive snow fence systems designed to protect Interstate 80 in southeastern Wyoming by trapping blowing snow establish the validity of the concept.

TABLER, RONALD D., AND R. A. SCHMIDT.
1973.

Weather conditions that determine snow transport distances at a site in Wyoming.
p. 118-126. *In The role of snow and ice in hydrology. Symp. on Properties and Processes (Unesco) [Banff, Alberta, Can., Sept. 1972] Proc. 2 vols.*

Measurements of total insolation and air temperature and relative humidity during all 1970-71 winter drifting events indicate average transport distances of 460 and 900 m for particle diameters of 0.010 and 0.015 cm, respectively.

TABLER, RONALD D.

1974.

New engineering criteria for snow fence systems.
Transp. Res. Rec. 506, p. 65-78. NAS-NRC, Wash., D.C.

Amount of blowing snow arriving at a site is estimated from an equation relating snow transfer coefficient, transport distance, and precipitation received over the contributing distance. Height and number of fences to provide required capacity are then computed. The system effectively prevents drifts, improves visibility, and reduces road ice.

TABLER, RONALD D.

1975.

Estimating the transport and evaporation of blowing snow.
p. 85-104. *In Snow Manage. on Great Plains Symp. [Bismarck, N. Dak., July 1975] Proc. Great Plains Agric. Counc. Publ. 73, 186 p.*

In an empirical process, the distance an average-sized snow particle can travel before it completely evaporates (sublimates) is calculated to account for the net effect of intricate relationships among temperature, humidity, radiant energy, and abrasive forces. Results agree well with measured snow accumulations in southeastern Wyoming.

TABLER, RONALD D.

1975.

Predicting profiles of snowdrifts in topographic catchments.
West. Snow Conf. [Coronado, Calif., Apr. 1975] Proc. 43:87-97.

A regression model requires only terrain data to estimate snowdrift profiles. Drift slopes are influenced by the terrain from 150 feet upwind to an equal distance downwind of the catchment lip. Applications in addition to highway design include reshaping strip-mined terrain to maximize onsite snow retention.

WYOMING HIGHWAY DEPARTMENT.

1972.

Fencing parries winter's thrusts.
The Highwayman 22(1):12-14.

First-year results of a cooperative agreement between the Wyoming Highway Department and the Rocky Mountain Forest and Range Experiment Station show the snow-fence system designed by R. D. Tabler and R. A. Schmidt, Jr., of the Station, to protect Interstate 80 in Wyoming was highly effective. Several miles of fence, most of it 12 feet high, greatly reduced plowing requirements and dramatically improved visibility.

Measurement Techniques, Instrumentation

CAMPBELL, C. J., AND CHARLES P. PASE.

1972.

Pressure bomb measures changes in moisture stress of birchleaf mountainmahogany after partial crown removal.

USDA For. Serv. Res. Note RM-221, 4 p.

The pressure-bomb technique detected highly significant changes in plant-moisture stress of mountainmahogany following 41 percent or more leaf-mass removal, but no significant reductions in stress when leaf mass removed was 36 percent or less.

CAMPBELL, C. J.

1973.

Pressure bomb measurements indicate water availability in a southwestern riparian community.

USDA For. Serv. Res. Note RM-246, 4 p.

The Scholander pressure-bomb technique detected differences in plant moisture stress between and among species, thereby delineating areas of high or low potential evapotranspiration within a riparian zone.

GARY, HOWARD L.

1976.

A tripod mount to aid in lifting heavy objects.

USDA For. Serv. Res. Note RM-305, 2 p.

Describes an easily constructed tripod that can be mounted on legs of varying length. When equipped with a sheave or block and tackle, the mount can accommodate a wide variety of hoisting needs.

HAEFFNER, ARDEN D., AND A. H. BARNES.*

1972.

Photogrammetric determinations of snow cover extent from uncontrolled aerial photographs.

Am. Soc. Photogramm. [Columbus, Ohio, Oct. 1972] ASP Tech. Sess. Proc., p. 319-340.

Overlapping, vertical aerial photos provide sufficient information for determining extent of snow cover in a small open area of mountainous terrain where accurate ground control is not available. Index measurements can be extrapolated to a much larger drainage.

HEEDE, BURCHARD H.

1974.

Velocity-head rod and current meter use in a boulder-strewn mountain stream.

USDA For. Serv. Res. Note RM-271, 4 p.

The velocity-head rod should not be used in boulder-strewn mountain streams unless the gaged section can be modified to obtain uniform flow. The one-point current-meter method will suffice for most operational purposes.

JAIRELL, ROBERT L.

1975.

A sturdy probe for measuring deep snowdrifts.

USDA For. Serv. Res. Note RM-301, 3 p.

Sections of hexagonal aluminum rod joined with pump couplings form a rigid probe that does not bend while penetrating ice layers. Bit design is important.

JAIRELL, ROBERT L.

1975.

An improved recording gage for blowing snow.

Water Resour. Res. 11(5):674-680.

The most important improvement is the efficient turntable design which allows the precipitation gage to be independent of the snow trap. The result is a high-quality chart record. Principal advantages include simplicity, low cost, and suitability for operation in remote areas lacking electrical power.

JOHNSON, KENDALL L., AND RONALD D. TABLER.

1973.

An enclosed weir for small streams in snow country.

USDA For. Serv. Res. Note RM-238, 8 p.

An enclosed sharp-crested V-notch weir provides trouble-free winter operation. A multiplate pipe arch with closed ends is fitted over an independent cutoff wall; the instrument shelter is mounted on the arch over a stilling well. Compared to conventional design, construction time was reduced 50 percent, total costs 40 percent.

JOHNSON, KENDALL L.

1974.

A sleeved pit gage for summer precipitation.

USDA For. Serv. Res. Note RM-256, 3 p.

Performance of a pit gage was greatly improved by using a 5-gallon cream can as a sleeve. Four years of experience have shown the improved pit gage to be nearly ideal for keeping the gage vertical and free of soil, and facilitating quick removal and reinsertion of the gages for periodic weighing.

LARSON, FREDERIC R., PETER F. FFOLLIOTT,* AND KARL E. MOESSNER.*

1974.

Using aerial measurements of forest overstory and topography to estimate peak snowpack.

USDA For. Serv. Res. Note RM-267, 4 p.

Where slope steepness and aspect vary widely and forest overstory size and density classes are intermixed, only topographic attributes need be measured. All of the tested photo scales were satisfactory. On nearly level sites where size and density classes are homogeneous, forest overstory attributes also must be measured.

LARSON, FREDERIC R.

1974.

Formulating conversion tables for stick-measure of Sacramento precipitation storage gages.

USDA For. Serv. Res. Note RM-276, 2 p.

These gages are usually built to specifications by local sheet metal companies where quality control is limited. This Note presents two mathematical models for estimating precipitation in locally constructed gages. A calibration technique is also described.

MARTINELLI, M., JR.

1972.

Take the plunge.

Ski Area Manage. 11(1):26-28.

The rammsonde is a simple, reliable device for measuring snow compaction or hardness. It can help the ski area manager evaluate trail maintenance techniques and results.

OZMENT, ARNOLD D.

1975.

Development and testing of a laser rain gage.

p. 185-190. In Vol. 5, Hydrol. Water Resour. in Ariz. and the Southwest. Proc. 1975 Meet. Ariz. Sect., Am. Water Resour. Assoc. and Hydrol. Sect., Ariz. Acad. Sci., [Tempe, Ariz., Apr. 1975.]

Precipitation is measured by scattering a beam from a helium-neon laser. Although calibration is still a problem, the laser gage does not disturb windflow, gives instantaneous rainfall rates, and can effectively sample large areas. Pairs of beams could measure interception.

SCHMIDT, R. A.

1975.

Analog temperature records from a linearized thermistor network.

USDA For. Serv. Res. Note RM-286, 4 p.

To overcome the inherent disadvantage of nonlinear output, a system was developed consisting of a thermistor network and operational amplifiers to produce a linear analog temperature record, either on strip charts or magnetic tape.

SCHOLL, DAVID G., AND ALDEN R. HIBBERT.

1973.

Unsaturated flow properties used to predict outflow and evapotranspiration from a sloping lysimeter.

Water Resour. Res. 9:1645-1655.

Both moisture outflow and evapotranspiration from sloping soils can be predicted from moisture content, pressure potential, and rainfall by using Darcian and water-balance methods. Estimating these factors on watersheds is limited by sampling problems associated with natural heterogeneity.

SCHULTZ, ROBERT W.

1973.

Snowmelt lysimeters perform well in cold temperatures in central Colorado.

USDA For. Serv. Res. Note RM-247, 8 p.

Comparison between lysimeter and snow-tube measurements of melt rates indicated that the lysimeters provided reliable measurements of snowmelt. The lysimeter frame did not noticeably affect the thermal regime of the snow within the lysimeter.

SOMMERFELD, R. A., AND F. WOLFE, JR.

1972.

A centrifugal tensile tester for snow.

USDA For. Serv. Res. Note RM-227, 4 p.

A new centrifugal tensile tester has been designed for snow samples. The new design corrects many of the deficiencies of the older design.

STEPPUHN, H.,* J. R. MEIMAN,* AND B. C. GOODSELL.

1972.

Automatic detection of water-borne fluorescent tracers.

Int. Assoc. Sci. Hydrol. Bull. 16(4):83-89.

A continuous, automatic, film system detects tracer concentrations of one part per billion, provides a time distribution of concentration changes, and combines low cost with ready portability. Field installations are self-operative for up to 10 days.

SWANSON, R. H.

1972.

Water transpired by trees is indicated by heat pulse velocity.

Agric. Meteorol. 10:277-281.

Daily total transpiration was linearly related to heat pulse velocities (HPV) measured once each day at noon or for periods centered at noon. Correlation coefficients were above 0.98. HPV was shown to be a function of transpiration and water movement into storage.

THOMPSON, J. R., AND A. D. OZMENT.

1972.

The Rocky Mountain millivolt integrator for use with solar radiation sensors.

USDA For. Serv. Res. Note RM-225, 8 p.

Electronic integration of a radiometer's millivolt signal is a practical and accurate means of obtaining hourly, daily, weekly, or long-term radiation values. Our integrator consists of four printed circuit boards, a synchronous bi-directional stepper motor, and 5-decade counter. Each integrator is calibrated to match the millivolt output of the radiation sensor, so that the counter reads directly in langleys. The totalizing of a signal from a typical net radiometer (with a 6.20mv/langley output) would be within plus or minus 1 percent over most of the positive signal range, but could be 5 percent too low at night when the sensor output is negative.

YAMAMOTO, TERUO.

1974.

Seismic refraction analysis of watershed mantle related to soil, geology and hydrology.

Water Resour. Bull. 10:531-546.

Isopachs, area-elevation curves, and structure contours were used together with drill cores, petrography, hydrographs, and soil information to interpret the nature and role of porous mantle in the waterflow behavior of small watersheds on a laccolith near Sturgis, South Dakota.

Multiple Use Relations

BAKER, MALCHUS B., JR., AND HARRY E. BROWN.
1974.

Multiple use evaluations on ponderosa pine forest land.
p. 18-25. In 18th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm.
Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-129, the
status-of-our-knowledge publication by the Rocky Mountain
Station. A copy of the Proceedings may be requested from the
Arizona Water Commission, Phoenix.

BAKER, MALCHUS B., JR.

1975.

Modeling management of ponderosa pine forest
resources.

Watershed Manage. Symp., ASCE Irrig. Drain. Div.
[Logan, Utah, Aug. 1975] Proc. 1975:478-493.

Manipulating forests on volcanic soils in Arizona showed that:
water-yield increases of 0.6 inch are realistic; harvestable timber
growth can be increased, even with reduced basal area;
understory plant growth and deer and elk habitat can be
improved; economic returns can be increased, even when
environmental factors are emphasized.

CARDER, D. ROSS.

1975.

Woods Canyon--a large scale watershed management
experiment: An explanation and interim report.

p. 43-46. In 19th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1975] Proc. Ariz. Water Comm.
Rep. 7, 51 p. Phoenix, Ariz.

Woods Canyon could become more a demonstration of methods
for improving multiple-use planning and management than for
improving water yields. Improved models will be used to predict
yield changes after various treatment alternatives. Existing
gaging stations and other field measurements will show accuracy
of model predictions.

CLARY, WARREN P.

1974.

Pinyon-juniper control--does it pay?

p. 26-29. In 18th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm.
Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-128, the
status-of-our-knowledge publication by the Rocky Mountain
Station. A copy of the Proceedings may be requested from the
Arizona Water Commission, Phoenix.

CLARY, WARREN P.

1975.

Multiple use effects of manipulating pinyon-juniper.
Watershed Manage. Symp., ASCE Irrig. Drain. Div.
[Logan, Utah, Aug. 1975] Proc. 1975:469-477.

Mechanical methods of pinyon-juniper removal are not likely to
increase water-yields; herbicidal treatments may. Herbage yields
increase after all treatments; deer response is generally neutral.
The more successful conversion projects about break even
financially.

DIETERICH, JOHN H.

1975.

Chaparral management: Its potential--its
problems--its future.

p. 47-51. In 19th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1975] Proc. Ariz. Water Comm.
Rep. 7, 51 p. Phoenix, Ariz.

Chaparral is now managed primarily by protection, rather than
by design. Research indicates that more intensive management
would modestly increase or improve wildlife habitat, water
yield, grazing capacity, and wildfire control.

HIBBERT, ALDEN R.

1974.

Water resources research on forest and rangelands in

Arizona.

p. 1-9. In Vol. 4, Hydrol. Water Resour. in Ariz. and
the Southwest. Proc. 1974 Meet. Ariz. Sect., Am.
Water Resour. Assoc. and Hydrol. Sect., Ariz. Acad.
Sci., Flagstaff.

A two-pronged research effort is underway to provide a sound
basis for managing water resources on Southwest forests and
rangelands. In addition to its ongoing research program, the
Rocky Mountain Station has joined with nine universities to form
the Eisenhower Consortium to improve our understanding of the
relationships between man and his environment.

HIBBERT, ALDEN R.

1974.

Chaparral research for water and other resources.

p. 30-36. In 18th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm.
Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-126, the
status-of-our-knowledge publication by the Rocky Mountain
Station. A copy of the Proceedings may be requested from the
Arizona Water Commission, Phoenix.

HIBBERT, ALDEN R., EDWIN A. DAVIS, AND THOMAS
C. BROWN.

1975.

Managing chaparral for water and other resources in
Arizona.

Watershed Manage. Symp., ASCE Irrig. Drain. Div.
[Logan, Utah, Aug. 1975] Proc. 1975:445-468.

About 21 percent of the 3.5 million acres of chaparral in Arizona
could be converted to grass to improve water and forage
production. The expected annual increase of 150,000 acre-feet,
however, would increase Arizona's total water supply only about
2 percent.

HORTON, JEROME S.

1972.

Management problems in phreatophyte and riparian
zones.

J. Soil Water Conserv. 27:57-61.

After the invasion of the aggressive tamarisk along streams,
rivers, and flood plains of the arid Southwest, removal of
phreatophyte vegetation for water savings was felt to be
paramount. Now recreational use, wildlife protection, honey
production, erosion prevention, and preservation of esthetic
values must all be considered for optimum management.

HORTON, JEROME S.

1974.

Management alternatives for the riparian and
phreatophyte zones in Arizona.

p. 40-42. In 18th Annu. Ariz. Watershed Symp.
[Phoenix, Ariz., Sept. 1974] Proc. Ariz. Water Comm.
Rep. 6, 60 p., Phoenix, Ariz.

Resume of USDA For. Serv. Res. Pap. RM-117, the
status-of-our-knowledge publication by the Rocky Mountain
Station. A copy of the Proceedings may be requested from the
Arizona Water Commission, Phoenix.

LEAF, CHARLES F., AND ROBERT R. ALEXANDER.

1975.

Simulating timber yields and hydrologic impacts
resulting from timber harvest on subalpine
watersheds.

USDA For. Serv. Res. Pap. RM-133, 20 p.

A dynamic simulation model determines the hydrologic changes
resulting from timber harvesting, and corollary models simulate
timber yields. Emphasis is placed on the 'planning unit' which is
defined by environmental characteristics, including
combinations of slope, aspect, elevation, and forest cover.

MYERS, CLIFFORD A., AND MEREDITH J. MORRIS.

1975.

Watershed management practices and habitat values

in coniferous forests.

p. 288-295. In Proc. Symp. Manage. For. Range Habitats for Nongame Birds [Tucson, Ariz., May 1975]. USDA For. Serv. Gen. Tech. Rep. WO-1, 343 p. Wash., D.C.

Application of watershed management practices in coniferous forests can produce thinned stands, cleared openings, and new plantations. Clearcutting patches to increase water yields has the greatest potential for changing nongame bird habitats. Changes in the vegetative cover will increase habitat diversity, which is frequently, but not always, beneficial to birds.

OTHER

*Private, State or Federal cooperator

BOSTER, RONALD S., AND WILLIAM E. MARTIN.*
1972.

The value of primary versus secondary data in interindustry analysis: A study in the economics of the economic models.

Ann. Reg. Sci. 6(2):35-44.

In a case study of two input-output models, one from primary data, one from secondary, neither statistical analysis nor projection comparisons showed the aggregative components of one to be better than the other. The model developed from secondary sources was quite adequate, and vastly less expensive.

CLEMA, JOE K.,* AND MICHAEL A. FOSBERG.

1974.

SENSNX--A general subroutine for the sensitivity analysis of simulation models.

Ann. Simul. Symp. [Tampa, Fla., Mar. 1974] Proc. 7:253-263.

SENSNX is a FORTRAN subroutine designed to evaluate the sensitivity of simulation models by two methods. The first method is based on the statistical error associated with the independent variables. The second is designed to determine the uncertainty of the fixed finite errors of the independent data.

KERBS, ROGER R.

1972.

Handy device for dispensing barbed wire.

J. Range Manage. 25:72-73.

The device is held vertically in the rear stake pocket of a pickup truck. It costs about \$6 to construct, reduces the possibility of wire entanglements, and frees one man of a two-man crew to do other work.

KOVNER, J. L., AND S. A. PATIL.

1973.

On the moments of the doubly truncated bivariate normal population with application to ratio estimate.

J. Indian Soc. Agric. Stat. 25(2):131-140.

The first four moments are obtained. From these, the movement estimators are obtained by an iterative procedure. These in turn are used to estimate the mean square error of the ratio estimator.

A numerical example from a biological population is presented.

MESSNER, HAROLD E., DONALD R. DIETZ, AND E. CHESTER GARRETT.

1973.

A modification of the slanting deer fence.

J. Range Manage. 26:233-235.

This slanting deer fence requires less mesh wire and shorter posts than the standard upright deer fence. The slanting fence blends well into forest and meadow backgrounds, and will withstand greater snow loads than existing slanting deer fences.

NICKERSON, MONA F., AND GLEN E. BRINK.

1974.

Publications from the Rocky Mountain Forest and Range Experiment Station, 1953-73.

USDA For. Serv. Gen. Tech. Rep. RM-6, 96 p.

Lists all publications, alphabetically by author, issued since the consolidation of the Southwestern and the Rocky Mountain Stations in 1953.

PATIL, S. A.,* J. L. KOVNER, AND D. C. PATEL.*

1974.

The distribution of the MLE of the uniform correlation coefficient in the multivariate normal population.

Ann. Inst. Stat. Math. 26:403-411.

Studies the distribution of the maximum likelihood estimator when the sample is taken from a multivariate normal population with uniform covariance matrix, and considers application of the distribution to testing and confidence intervals. Also gives critical values of the likelihood ratio test statistic.

SOMMERFELD, RICHARD A.

1974.

An automatic data acquisition and reduction system.

USDA For. Serv. Res. Note RM-260, 4 p.

Up to 41 channels of slowly varying data are multiplexed into a very slow speed analog tape recorder, then played back and punched on paper tape for conventional use at speeds up to 1,000 times as fast as the recording speed. Total system accuracy is within 0.3 percent.

WENGER, KARL F.

1975.

More on the application of research findings.

J. For. 73(8):477-480.

Application of research findings is part of the larger problem of information retrieval and use. Since the effort needed to do this job adequately is too great for individuals with full-time management responsibilities, a team of technical experts on the manager's staff is needed to serve as information processors.



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Phone: (505) 766-2384 (FTS-474-2384)

Mine Spoil Reclamation in the Southwest: **Earl F. Aldon**

Forestry Sciences Laboratory
Northern Arizona University
Flagstaff, Arizona 86001
Phone: (602) 774-5261 Ext. 1467 (FTS-261-1467)

Culture of Southwest Conifers and Aspen: **Gilbert H. Schubert**

Multiresource Management Analysis and Evaluation—Southwest: **D. Ross Carder**

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Habitat Criteria Development for Southwestern Wildlife: David R. Patton
Multiresource Response Evaluation—Southwest Watersheds: Leonard F. DeBano

**seeking better ways to manage
natural resources on forest
and range lands in the great
plains, central rockies and
southwest**

U. S. Department of Agriculture, Forest Service.

1976. Rocky Mountain Forest and Range Experiment Station: A list of published research, April 1, 1972 through March 31, 1976. USDA For. Serv. Gen. Tech. Rep. RM-31, 59 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Provides an annotated list of Station publications printed during the research years April 1, 1972 through March 31, 1976. Publications are organized by subject categories: Forest Management, Range and Wildlife Habitat Management, Watershed Management, Fire and Atmospheric Sciences, Forest Insects and Diseases, Recreation, Resource Assessment and Economics, Forest Products, Other.

U. S. Department of Agriculture, Forest Service.

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U. S. Department of Agriculture, Forest Service.

1976. Rocky Mountain Forest and Range Experiment Station: A list of published research, April 1, 1972 through March 31, 1976. USDA For. Serv. Gen. Tech. Rep. RM-31, 59 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

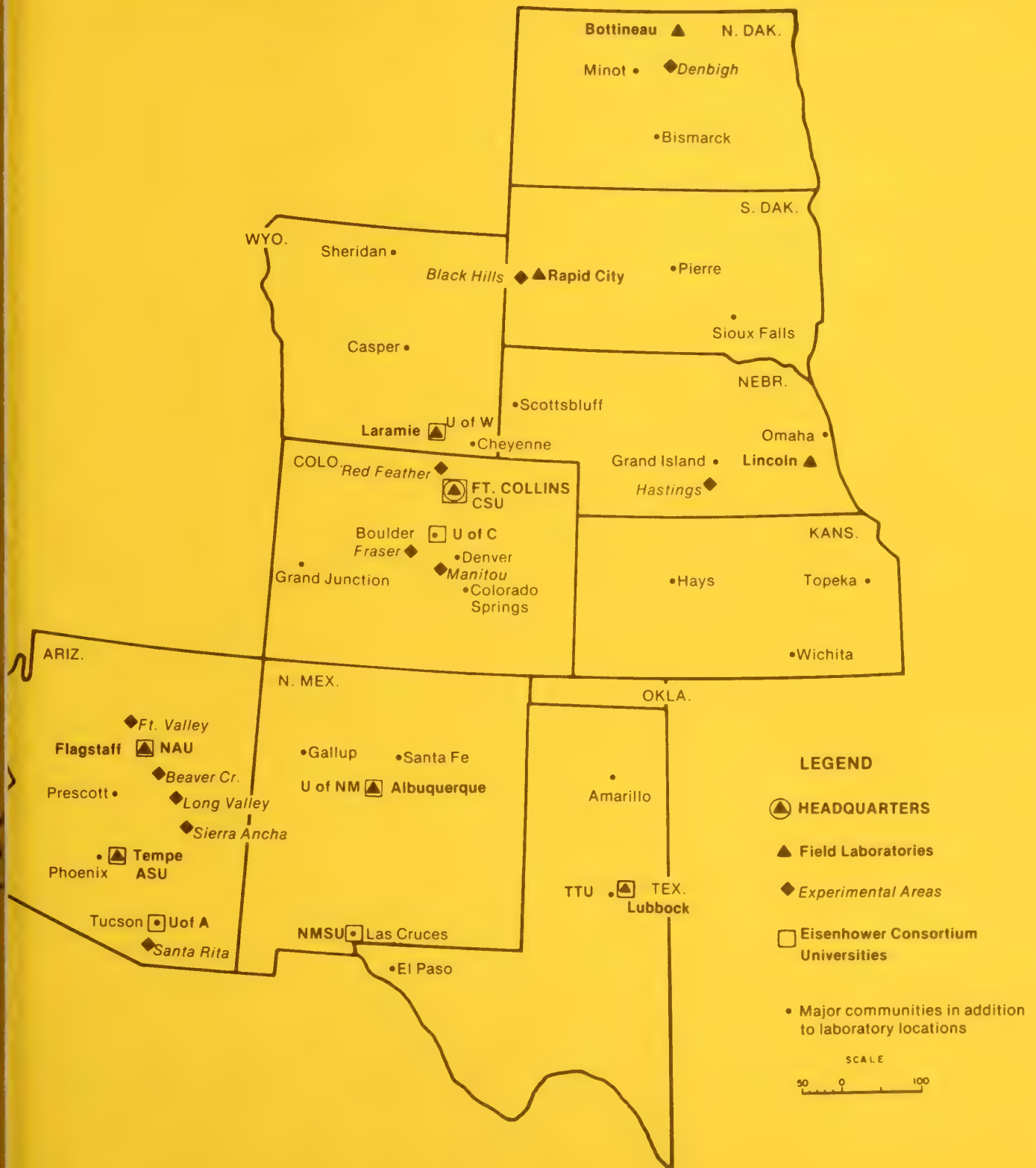
Provides an annotated list of Station publications printed during the research years April 1, 1972 through March 31, 1976. Publications are organized by subject categories: Forest Management, Range and Wildlife Habitat Management, Watershed Management, Fire and Atmospheric Sciences, Forest Insects and Diseases, Recreation, Resource Assessment and Economics, Forest Products, Other.

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

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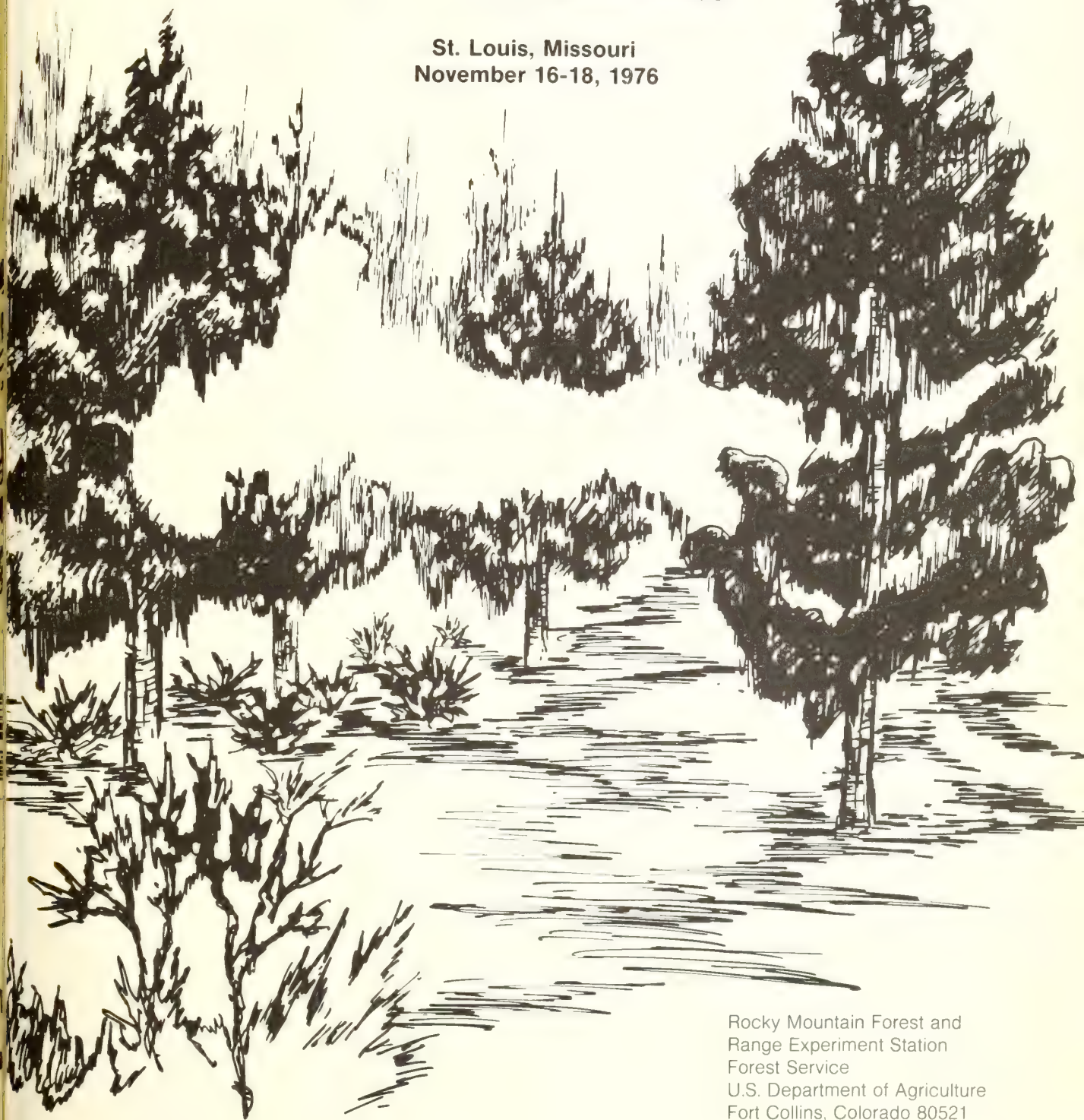






Proceedings of the Fourth National Conference on Fire and Forest Meteorology

St. Louis, Missouri
November 16-18, 1976



Rocky Mountain Forest and
Range Experiment Station
Forest Service
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Fort Collins, Colorado 80521

Baker, Douglas H., and Michael A. Fosberg. [tech. coord.]
1976. Proceedings of the fourth national conference on fire and
forest meteorology, St. Louis, Missouri, Nov. 16-18, 1976.
USDA For. Serv. Gen. Tech. Rep. RM-32, 239 p. Rocky Mt. For.
and Range Exp. Stn., Fort Collins, Colo. 80521.

Research papers contained in this volume are based on presentations at the Fourth National Conference on Fire and Forest Meteorology held in St. Louis, Missouri, Nov. 16-18, 1976. Each session contains a number of invited papers surveying the session topic, as well as contributed papers. Sessions were held on: land managers' needs for weather service and advice; current weather forecasting capabilities; fire danger and weather; atmospheric aspects of forest insect and disease control; meteorology and land use; and influence of atmospheric pollutants on biological systems.

Keywords: Forest meteorology, fire danger, fire weather, atmospheric pollutants.

About the cover:

*Artist's interpretation of smoke drift
through a forest clearing.*

Proceedings of the
Fourth National Conference on Fire
and Forest Meteorology

St. Louis, Missouri
November 16-18, 1976

Technical Coordinators:
Douglas H. Baker
Boise Interagency Fire Center
and
Michael A. Fosberg
Rocky Mountain Forest and
Range Experiment Station

Cosponsored by: Society of American Foresters; American Meteorological Society; and Rocky Mountain Forest and Range Experiment Station, central headquarters maintained at Fort Collins in cooperation with Colorado State University.

Preface

The Society of American Foresters and the American Meteorology Society are service-oriented professional organizations. Each is dedicated toward advancing the capabilities of its membership in their respective fields. This conference, the fourth of its kind, is designed to provide a common meeting ground for the two relatively disparate disciplines.

Its purpose is to explore the special weather forecast needs of forest and grassland managers, the extent to which the needs are being met, and to investigate possible directions of change. The participants, speakers and listeners alike, will determine the effectiveness of the conference, more by their subsequent actions than by those displayed during the meeting.

On behalf of the host, the Society of American Foresters, sincere thanks are extended to the members of the Missouri Chapter of the Society of American Foresters for their excellent effort in providing the facilities and local arrangements for the Conference.

Quick publication of these proceedings depended on the cooperation of the authors in preparing their papers in final form, ready for photo-offset reproduction.

Foreword

The fourth of a series of conferences jointly sponsored by the Society of American Foresters (SAF) and the American Meteorological Society (AMS) was held at St. Louis, Missouri, November 16, 17, and 18, 1976. The conferences have been generated by the Fire working group of the SAF and the Fire Weather meteorologists in the AMS, and have, in the past, been directed primarily at fire-weather forecasting.

The 1976 program was developed in recognition of the expanding needs of Land Resource Managers for meteorological services. These needs include fire-weather forecasting, in addition to specialized services for pest management, recreation, forest operations such as harvesting, site preparation and reforestation, and range management.

During this conference, Federal, State, university, and private participants defined their varied weather-related concerns. The meteorologists, Federal, State, and private, provided some insights into the abilities, limitations, and problems which are a part of developing service policies.

Some examples of statements developed in the conference are:

- Resource managers expressed a need for well-equipped weather stations, operated year round by the land

management agencies, to provide weather data not currently available to meteorologists.

- The National Weather Service stated a policy of providing special emphasis on forestry meteorology, including fire-weather forecasting.
- Land managers defined an urgent need for land management agencies to develop meteorological interpretive capabilities within their organizations.
- University spokesmen expressed the need for the inclusion of meteorology in forestry curricula and for career opportunities for university-trained meteorologists in land management agencies.

These are not unusual statements of policy and need. Placed in the context of this conference, however, with speaker presentations and discussions providing emphasis and reinforcement, the tone of the conference implied increasing attention toward the use of meteorology in land resource management.

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Keynote Address

Rexford A. Resler^{1/}

Today we are living in what has been appropriately described as the age of the environment. As meteorologists, foresters and forest-meteorologists, we have a vital responsibility in this new age. Much of the task of balancing very real resource needs with environmental constraints will fall to us.

There was a time not too long ago when many thought of the environment as essentially fixed and unchanging. Today, we know that this is not the case. Our knowledge of the environment, and of the natural resources, has multiplied many times over. Now, we have to seek the information, knowledge and skills required to harmonize human needs for resource use with environmental safeguards. And, as the old song goes, "you can't have one without the other," although there are those who would advocate all-out resource use without environmental safeguards or, at the other extreme, environmental protection achieved at the cost of very limited resource use. We can not side-step the issue. The problems of environmental management must be attacked head-on, and I believe our profession must play a key role in finding realistic, workable solutions.

Forestry and the atmospheric sciences may well provide some of the most fundamental contributions toward shaping our future environmental programs. Let's examine some areas where we are already working together, and others where we should be working together.

Perhaps no other issue today commands more attention, from both government leaders and the man-on-the-street, than the problem of energy. The gloomy statistics on world fuel reserves are only one facet of an immensely complicated issue. We are now becoming aware of the great impact which accelerating use of fossil fuels may have on our atmosphere--and, in turn, on the total climate of the earth. I don't need to tell you that combustion of fossil fuels produces significant amounts of carbon dioxide that is

injected into the atmosphere, where it enters the carbon cycle. If the rate of production exceeds what can be used by the forests and oceans, the excess becomes a permanent constituent of the atmosphere, where it greatly enhances the "greenhouse effect". I am told that theoreticians have projected a rapid warming in the earth's atmosphere after about the year 2000--resulting from the excess carbon dioxide released by burning these fuels.

This problem has a forestry component. The absence of sound land and forest management in some parts of the world is contributing significantly to the CO₂ problem. The great tropical forests represent one of the principal reservoirs for storing excess carbon. If they are harvested too quickly, without proper management, as seems to be the case in some areas, we will soon begin to increase the carbon dioxide pollution.

The handwriting is on the wall, and although the interpretation of its message may vary somewhat, the conclusion seems inescapable: unless we develop and practice management techniques to restore the great forests of the world while finding suitable substitutes for fossil fuels, we may face grave climatic difficulties in a few decades.

While I am on the subject of climatic change let me just mention another opportunity for meteorologists and foresters to work together. I don't think I need to offer data to convince you that forests, to a certain extent, make their own climate and strongly influence the climate of surrounding areas. Some scientists have hypothesized that the advance of the world's deserts has resulted from inadequate management of the forests and rangelands that formerly occupied these sites. I don't know the current state of such theories, but I do know that Forest Service studies very clearly show a strong relationship between forest vegetation systems and the atmospheric environment.

One of the most pressing problems involves the effects of pollution on the trees themselves. Air pollution has caused loss of vigor and severe mortality in ponderosa pine stands in southern California and in other conifers and hardwoods in the East. Coupled with the increasing acidity of the precipitation, particularly in the northeastern United States,

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these matters must command the immediate concern of our professions if we are to maintain the vegetative systems necessary for a quality environment.

The issues which I have discussed so far are fundamental and universal in scope. Now I'd like to turn to some of the day-to-day management options which will also require the talents of both foresters and meteorologists. Cooperation in forest protection comes to mind first. There is a long history of close collaboration between foresters and meteorologists in fire control. As you probably know, the Forest Service view concerning the role of fire in the forest is changing--from one of fire control to the broader concept of fire management. Fire management involves both use of fire and protection from fire, recognizing that fire of itself is neither good nor bad, except as its effects promote or hamper the management objectives for the land.

A moment's reflection will tell you that this view of fire requires a far more intense and sophisticated use of weather information than was needed in the past. Take, for example, those approved fire plans that authorized exceptions to the "10 a.m. policy." The need for accurate weather data, reliable predictions and their proper application to fire behavior projections are far greater than under the more traditional policy. As a matter of fact, it is not an overstatement to say that the success of this new fire management program will depend almost totally on the quality of the meteorological support which it receives.

While we know a great deal now about how meteorology and forestry should be joined in fire management, we do not have the same level of knowledge for our insect and disease control programs. It is obvious that weather conditions play a decisive role in the outbreak and spread of insects and disease. But we have no means of systematically incorporating these effects into our control strategies or into the day-to-day decisionmaking. I am very pleased to see that this conference has set aside an entire session for the discussion of this problem.

As land managers we are also faced with a major task in land management planning, which requires help from our meteorologist colleagues. The Clean Air Act and the subsequent implementing regulations require that each State classify

its land into three categories, ranging from areas in which any degradation of air quality would be prohibited, to areas which would tolerate pollution levels up to the national or local standards. The last Congress considered, but did not pass, legislation which would have placed areas such as National Parks and classified wilderness in class 1, thus prohibiting any degradation of air quality. Since air pollution can travel long distances from the sources, non-degradation air quality standards could have a profound effect on land use decisions and benefits. There's little doubt that similar legislation will again be introduced in Congress.

Meteorologists will have to help land use planners find the answers to a number of questions. For instance, how large must buffer zones around class 1 areas be in order to provide sufficient dilution to meet the required air quality standards? What constraints will these buffer zones place on forest and range practices and use of our renewable resources? And what are the cost implications? Who is going to pay for them?

In another area of current concern I should mention the Resources Planning Act, calling for a continuing assessment of all the multiple resources of the Nation's forests and rangelands. This requirement is creating a kind of revolution in Forest Service procedures--a welcome revolution, I might add. To project information properly, we must make extensive use of models for forest productivity of timber, water, wildlife, and even the social values and markets for recreation. In many areas the data requirements for these models demand meteorological and climatological information. Water and air quality are closely related to each other and form one of the resources to be assessed.

We live in a time of great challenge. One challenge is to accommodate the rapidly expanding volume of human needs for goods and services. Another challenge is to safeguard the delicate balances that make this planet Earth the only habitable place in the solar system and, so far as we know today, even in the entire universe. Forestry and meteorology promise us a perfect combination for meeting such challenges created in this age of the environment. I urge you to unite your efforts in this endeavor.

Session I

Land Managers' Needs for Weather Service and Advice

Chairman: Sam Cobb

State Forester

Pennsylvania Bureau of Forestry

Needs of State Forest Organizations¹

J. E. Schroeder^{2/}

Land managers today are concerned with needs generated by an expanding population which exerts ever-increasing political and economic pressures on an ever-diminishing wildland base. Our position as land managers and meteorologists needs to be one of constantly evaluating our changing needs and working together to develop the best system we can which will meet these needs.

INTRODUCTION

When I was invited to present the Needs of the State Forest Agencies for Land Management Weather Service and Advice, I recalled a similar assignment in Boise, back in 1971. I believe Bill Sullivan, who has a part in our second session here today, chaired that panel. However, the topic then was about fire weather needs. Today's concerns relate to the needs for weather service in the total land management program. Today we have broad based land managers concerned with an expanding population which exerts ever-increasing political, social, and economic pressures on a constantly diminishing wildland base. Environmentalism and concern for land use have become a way of life. Land managers and meteorologists have their work cut out for them to meet and hopefully stay ahead of the needs generated by these pressures.

CURRENT SITUATION

I'd like to begin by talking a little on the situation currently facing the various state agencies, the needs for weather services, and the use the states are making of services now available.

In the five years since I last discussed with you the fire management needs in the United

States, the situation has not changed very much. Each year we are still averaging more than 100,000 wildland fires which consume over 1 1/2 million acres. To meet this fire load, along

with other land management needs, the states employ the use of weather services according to the need. Service needs may vary according to acreage protected, number of fires, fire severity, hazard and risk. Other factors which affect service type and use are organizational peculiarities, variations in legal responsibilities, land use patterns, ownership, and degree of environmental sensitivity.

The use of weather service by the states has not changed much either -- primarily because the service offered is basically the same that has been provided for many years. Service ranges from using whatever public forecast is available, to special service forecasts, to the level of service Oregon has used for some time. In Oregon, the forecaster is fully integrated into the agency operations and his talents are used fully. Analysis, field service, system development and other user needs become an important part of the weather service pattern. This is the level of service that the states need if they are to meet the challenges of the environmental age in which we now live.

USER-PRODUCER RELATIONSHIPS

Now let's examine the relationship between the weather service and the state land and fire management agencies. First we need to state the objective of the weather service in general and the fire weather forecaster in particular. Thinking of the forecaster as a producer, the objective of the producer is to meet the weather

^{1/}Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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needs of the user.

In order for the producer to best meet these needs, he first has to develop a good working relationship with the user. The best way to accomplish this is to integrate the producer right into the user's organization. This can be accomplished in two ways. Wherever possible, the producer should be located at a headquarters of the user, with the headquarters selection to be based on individual user needs. If this is not possible or desirable because of geography, number and variety of users or other reasons, the producer should be located as close as possible to the user. With this inter-agency integration the forest manager-meteorologist team is better able to address the variety of problems and needs. The system produces improved mutual understanding, communication and training opportunities for the forest manager and the meteorologist alike.

FIRE WEATHER SERVICE ORGANIZATIONAL DEVELOPMENTS

Turning our attention to some of the things that have happened in the weather service organization during the past several years, back in 1971, I reported on two trends which I felt weakened these strong user-producer ties which are so greatly needed if we are to reach our mutual objective. One was integration of fire weather meteorologists and other specialists into the general forecasting system and the other was centralization. We were particularly concerned about the integration of specialists because it undermined the weather service objective. We opposed it then and we still oppose this type of organizational integration. Meteorological service to our land managers has continued to decline in the face of increased and broader needs. Our concern about this problem is greater than ever.

CURRENT NEEDS

Now, let's talk about some of the other key needs in the present weather service:

(1) Communications. As mentioned earlier, the need for weather service is no longer confined to just fire related activities -- it is needed to respond to such activities as scheduling reforestation, smoke management, forest aviation, spraying, seeding, fertilization, nursery activities, surface transportation, photography, and freeze, wind and water warnings. A complete user-producer teletype intertie is needed if we are to adequately serve these new and expanding fields of forest weather.

(2) Additional Weather Data: Another current need is for additional weather data. It seems that this goes hand-in-hand with the ever-increasing complexity of use and need facing the forest manager and the meteorologist. Two things that come immediately to mind are the need for additional upper air data and standardized and upgraded weather observation stations, including automatic data collection.

(3) Forecasting. Then, of course, there is the usual laundry list of needs in the area of forecasting. Some of these are tailoring forecasts to areas of homogeneous climatology, improving accuracy, providing seven-day-a-week service, and detailing of long-range forecasts. Most important, the National Fire Danger Rating System is reaching the final development stage. John Deeming will give us the latest developments tomorrow. At any rate, it looks good. We should look forward to full adoption by all agencies and tailoring our forecasts to this system.

FUTURE NEEDS

Now I would like to discuss our future needs and to do this I am going to confine my remarks to the four subjects of (1) environment, (2) research and development, (3) planning and projection, and (4) budgeting.

(1) As I stated at the outset, land management agencies are rapidly becoming transformed into environmental agencies concerned with a variety of land uses. As this transformation takes place, there also needs to be a transformation in weather service. I don't think this point can be emphasized enough. Not only is the weather scope being broadened to new fire and land management related fields, but the period of forecasting need is also being extended. As an example, smoke management requires more detailed service on a year-round basis. We need to be taking a real good look at all these new areas which keep springing up and try to develop an environmental approach so that we can meet the challenges as they arise.

Just to illustrate the changing pattern in forecasting needs, in 1975 the Salem, Oregon, Fire Weather Office issued 513 smoke management advisories, 346 fire weather forecasts, 120 spraying advisories, 9 nursery advisories and 9 burning advisories. Smoke management advisories are becoming far more detailed. For example, smoke management forecasts routinely forecast timing and velocity of sea breezes through coast range passes in western Oregon. Spraying forecasts are ever-increasing primarily to meet the needs of herbicide applications in

reforestation and the challenges of large scale insect control projects, such as the Tussock moth infestation which plagued the northwest states during the past few years. In many instances continuous field forecasting is required in order to get these jobs done. Nursery forecasting has also been on the increase. Nursery managers are concerned with minimum temperatures, abnormally warm or cold periods, snow and heavy rainfall. Weather conditions are extremely important to lifting operations, tree damage and survival.

In addition to advisories and forecasts, almost daily pilot briefings are conducted for aerial photo projects, insect and disease surveys, and air transportation.

(2) Research and development are platforms of progress in weather service just as they are platforms in other fields. Looking ahead on the program, I note that you will be hearing about some specifics in research, especially on Wednesday and Thursday. I only want to emphasize the need to continue and to push forward in this direction. But before I leave this subject, I would like to pass on some of the highlights of a meeting held last May in Portland, Oregon, where 35 top managers, meteorologists, teachers and researchers gathered to address the topic "Meteorological Needs in the Pacific Northwest". Although these highlights expressed here are regional in nature, I am sure they have meaning to all of us. First, the group expressed a need for greater application of climatic data to land use management. Examples cited were frequency and severity of drought, effect of precipitation on roads and soils, the development of resource cost to loss ratios based upon weather occurrence and the selection of recreation sites.

Second, the group endorsed NOWCAST -- a pilot program proposed in Oregon utilizing a television network for a continuous dissemination of weather information. We see great possibilities for this program, particularly in the areas of fire prevention, regulated use of wildlands and smoke management.

Third, this group also emphasized a theme I have already mentioned several times in my remarks here today. That is the increased need for expanded weather service for such land management activities as reforestation,

spraying, aerial surveys and general air operations and road construction and oiling.

(3) Planning and projection are closely aligned with research and development. What we need to accomplish here is to project the entire future land management system. Then we need to project the weather service that will be needed to serve this system. The last projection for fire weather system needs was incorporated in the "Federal Plan for a National Fire Weather Service" which outlined a nine-phase improvement plan to be achieved during the 1968-1972 time period. Currently, about four and one-half phases -- or about half the plan -- have been completed; right where we were five years ago. We are still behind schedule on this improvement plan and we need to catch up.

(4) This brings me to the last of the four subject areas I outlined in beginning the discussion on future needs. This is one dear to all our hearts -- money. There seems to be a perennial problem with budget deficiencies in the weather service, just as we have everywhere else. The state agencies are concerned about this problem and stand ready to assist in any way they can. One possible way to assist would be to follow the procedure used in obtaining a restoration of Clarke-McNary allotment funds. In this effort the state foresters pursued a unified and vigorous approach through their respective delegations in Congress to achieve the goal of increased funding for this vital program.

CONCLUSION

I have attempted in this presentation today to discuss the present services and future weather needs without reservation. In conclusion I would like to add that our position as meteorologists and forest managers needs to be one of constantly evaluating our changing needs and working together to develop the best user-producer system we can which will meet these needs.

I greatly appreciate the opportunity to appear here today. If the program is any indicator, this should be the best meeting we have ever had.

Thank you.

Land Managers' Needs for Weather Service and Advice¹

Jack F. Wilson^{2/}

Abstract. Fire weather needs in the U.S. Department of the Interior are highly variable both as to the missions and philosophies of the eight agencies involved. Weather requirements of USDI agencies range from short range meso scale data required by fire line personnel through the full range of weather services to the long range outlooks needed for seasonal planning purposes.

INTRODUCTION

Land management need for weather service and advice within the Department of the Interior is far too broad a topic for discussion at this session. The geographic range and the program complexities embraced by the USDI would require the consideration of all facets of weather services and would encompass such an extensive area of discussion as to be unmanageable. So, with your permission, I'll narrow this topic down to fire management needs within the USDI, recognizing that this topic also is broad.

While it might be somewhat elementary to many of you, the USDI supports fire missions in eight of its agencies, and vastly differing weather needs exist for each agency. Let me cite examples of these missions and philosophies.

AGENCY MISSIONS AND PHILOSOPHIES

Bureau of Land Management

In BLM, my own agency, the overall mission is briefly defined as "to manage all the resources for which it is responsible to provide maximum public benefit both currently and in the future, and with full consideration for good conservation practices and for protection and enhancement of the environment. (USDI Manual 135.1.2)"

Its fire philosophy briefly states, "take aggressive action on all new fires with sufficient force to contain the fire in the first burning period." If it escapes, the policy is to back off and assess resource values, costs, rehabilitation possibilities and environmental damage, and man or not man accordingly. (BLM Manual 9210.06C)

National Park Service

The mission of the NPS "is that portion of the public lands are reserved from settlement, occupancy, or sale and set apart as public parks or pleasuring grounds for all people. (USDI Manual 145.2) Their fire philosophy is best enumerated in Staff Memo 72-12." While some natural areas with a history of naturally ignited fires, or historic areas with a fire subclimax setting, may need to significantly change their plans and programs, other areas will continue full fire "control."

Bureau of Indian Affairs

BIA has the mission to encourage and train Indian and Alaska Native people to manage their own affairs under the trust relationship with the Federal Government; to facilitate full development of their human and natural resource potentials; and . . . to utilize their skill and capabilities in the direction and management of programs for their benefit. (USDI Manual 130.1.2)

Insofar as their fire policy is concerned, the best philosophy can be gleaned through reading 53 IAM 12.4. In essence, it is a control philosophy and is as one would expect in view of the trust nature of BIA's responsibilities. BIA has, however, been in the lead in the use of fire in forest management,

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

²/BLM Director, Boise Interagency Fire Center, Boise, Idaho.

particularly in the southwestern United States.

Fish and Wildlife Service

The F&WS mission is to (1) assist in the development and application of an environmental stewardship ethic for society based on ecological principles, scientific knowledge of fish and wildlife, and a sense of moral responsibilities, (2) guide the conservation, development, and management of the nation's fish and wildlife resources, and (3) provide the American public with opportunities to appreciate, understand and use wildlife resources. (USDI Manual 142.1.1B)

Their fire philosophy is not set forth in any guidelines that I can find, but a general ethic exists within F&WS that better grass and wildlife forage will replace existing vegetation if fires in brush and grassland are set, or allowed to burn. Fire suppression on wildlife refuges are usually contracted to other protection agencies.

In addition within the Department, several other agencies have minor fire activities. These agencies include the U.S. Bureau of Reclamation, the Bureau of Mines, the Bonneville Power Administration, and the Office of Territories.

NECESSARY FIRE WEATHER FORECAST AND SERVICES

From all the foregoing, you would expect the needs for fire weather services to be varied. The need for weather service of a BIA worker to burn logging slash on the White River Agency in Arizona is far different from that of a Park Ranger in Sequoia National Park who must determine whether or not to take action on a fire.

So also are the needs for weather services different for succeeding higher echelons in the administrative chain. A very specific site requirement exists for a Fire Boss who needs to know what winds to expect in Whiskey Creek at 3 p.m. because winds are critical to him for control purposes. His boss, a District Fire Control Officer, may be more interested in a broader forecast for tomorrow for his district. His counterpart at the State level needs the same kind of information, but on a much wider geographic base. A major coordination center, such as Boise Interagency Fire Center, needs longer range, broader geographic data, and can utilize less precise or verifiable data. These data include continuous monitoring of antecedent moisture and fuels growth conditions, as an example the Palmer Drought Index, moisture indices, seasonal accumulated stream flow,

soil moisture information, etc. Beyond that, there is a need for data systems to massage the extensive climatological data into fire planning systems. For example, in 1965 fire danger ratings were among the highest recorded, yet there were few large fires in 1965. Why? The answer was found in the painstaking analysis of relative humidities for that year. While they were only 2 percent to 3 percent higher than usual, that was enough to keep large fire incidence low.^{3/}

Forecast/outlook information often strongly influences higher level decision-makers regarding major mobilization, prepositioning, or demobilization decisions. We recognize the scientific and perhaps legalistic constraints with which the National Weather Service must contend, and many other factors are also considered, but we need the best advice on pending weather events that we can get. Frequently, we get a lot of benefit from such questions as: Will the lightning storm be wet or dry? When will the front hit Kimama? And so on. We know these are judgment factors and are often the fruits of years of experience, and we'll continue to ask these questions--recognizing full well the limitations that are built in.

Another emerging area that needs climatological analysis and fire weather counsel is in fire management area planning. The NWS has not been involved very much here. What weather parameters should be built into management prescriptions? An example of what can happen without this sort of input occurred in Michigan in late August on the Seney Wildlife Refuge. A fire that under normal weather conditions for that area would not have become a problem, became a costly suppression problem under the severe drought conditions that exist this year. If the parameters are properly identified, then the assessment and monitoring systems become important and need Weather Service guidance.

And finally, a very important aspect is to recognize the need and to acknowledge the excellent service that Fire Weather Forecasters are providing to the fire training programs. The course development, tasking, and curriculum content, as well as the instruction itself, are vital to training fire personnel. As fire management becomes much more costly and sophisticated, the need for quality weather inputs will increase at all management levels. I would hope and anticipate the National Weather Service will make increased resources available to help fire control agencies continue to meet their changing needs.

^{3/} Personal efforts supported by Charles Seaverson, NWS 1965/66.

Department of Agriculture Needs for Specialized Weather Forecasting¹

W. R. Tikkala ²/

The historic need for special weather forecasting has been identified with fire protection. Supplemental weather stations have been installed and operated for this purpose. The need for specialized weather service in other forest management operations should be recognized and appropriate measures should be taken to provide the basic weather information to the forecasters. The procedures for inclusion of weather judgements in resource management should be developed. Special forecast services provided by NWS should be strengthened and expanded.

This conference is an extremely interesting one. The first three joint meetings were dedicated mostly to the scientific aspects of fire weather. The managerial and policy making portions of the meteorology--forestry mix have not been a subject for discussion in these meetings. In this respect we have probably been guilty of the "talking to ourselves" syndrome. This conference will not only give us a chance to examine the full scope of forestry needs in the special forecasting area of the meteorological services, but will also permit some examination of the various approaches to meet these needs.

For many years foresters and meteorologists have enjoyed a close working relationship, especially in responding to emergencies. Most of the emergencies have been fire related, although occasionally hurricanes and floods have been involved. The increasing needs and demands for forest resources have created an expanded set of more specific requirements for meteorological information to support planning and decision making by forest managers.

We might begin by examining some of the general characteristics of the meteorological information required by management. First of all, the information must be timely in that it

must relate directly to those time periods over which the decision will be applicable. It must be site specific; that is, the information must be applicable to those locations on which management decisions will focus. Finally, it must have proper form and quality for direct use in decision making.

To see the evolution of these needs, we might explore some of the historic approaches to the use of meteorological information, as practiced by foresters in the Department of Agriculture. These uses were identified early in the management planning of the U. S. Forest Service, the primary forest management agency in the Department. There was quick recognition of the importance of predicting weather in the fire protection segment of resource planning. Supplemental weather stations were developed at district headquarters, and firemen became adept at relating temperature, wind, and humidity to the incidence and growth of fires. Fire Weather forecasters were assigned by the National Weather Service to provide close scrutiny to the weather elements that affect fires. Weather stations became known as fire danger stations, and were manned, financed, and supervised by fire control personnel.

However, the management of forests and grassland has expanded beyond the fire protection status which spawned the fire danger station. Some of the areas where meteorology should be of concern to foresters are:

¹/ Paper presented at the Fourth Conference on Fire and Forest Meteorology, St. Louis, Missouri - November 16-18, 1976.

²/ W. R. Tikkala, Director, Cooperative Fire Protection, U. S. Forest Service, Washington, D. C. 20250.

- Reforestation of lands which have been deforested through one means or another, is an extremely critical undertaking. Precise

knowledge of amounts, kinds, duration, and timing (seasonal) of precipitation in an area to be reforested is essential. Depth of snow cover, moisture content of the soil, probability of frost, and selection of the proper tree species all have a bearing on when and how to reforest.

- Logging should be planned around soil moisture, snow depth, periods of heavy rain, and periods of low humidity. Such planning during sale preparation can have a tremendous beneficial effect on sale layout, landings, equipment requirements, debris utilization, and reforestation. A sale designed for helicopter operation could be considerably more attractive if the prospectus listed the average number of hours per day and days per month a helicopter could operate.

- Engineering--the design of roads, culverts, bridges, administrative sites all require precise knowledge of kinds and amounts of precipitation, wind direction and probable velocity, and other related weather information.

- Recreation--both winter and summer recreation planning involves the impact of weather on humans. Snow, ice, winds, and avalanches have a marked effect on the recreationist, as do high summer temperatures, lightning, storms, possible wildfires and drought. Planning recreation facilities suggest a need for close liaison with meteorologists.

- Insect and disease management in the forest environment is dependent on accurate meteorological information. Forest pest population fluctuations are controlled principally by food and weather. Our ability to anticipate pest population eruptions rests directly on our knowledge of host susceptibility to attack and understanding of weather patterns which are favorable to the pest. The successful execution of aerial suppression operations to control forest pest outbreaks is also influenced by meteorological factors. The ability to accurately predict pest development rates and meteorological episodes potentially detrimental to treatment effectiveness is extremely important in timing aerial suppression projects.

I mentioned earlier the close operational ties between fire protection and the forest network of weather stations. There are about 1800 of these stations nationwide, operated by

State and Federal agencies. Their use is almost exclusively keyed to fire danger. These stations supplement National Weather Service facilities, and serve to fill gaps in the data collection process. Perhaps one of the keys to expanding cooperation with meteorologists in forestry related weather operations is the use of these weather stations. We should consider year round operations, multiple purpose locations, and broad scale analysis of data.

Forecast centers, as envisioned by the NWS will provide computerized predictions of weather, on a large scale, based on the best predictive skills available in the programming and interpretation of weather inputs. On this scale, a reasonable product should be the best mass-use, general purpose forecast.

The person who is planning to put a large crew into action setting fire in 40 ton per acre slash cannot rely on mass-use, general purpose forecasts. He is playing with fire, in the true sense of the term, when he commits himself to such an action without the most precise weather information available. For this reason, specialized, localized, unique forecasting services are required. They are not required however in every month of the year in most locations.

The analysis of fire weather patterns, high snowfall areas and other weather elements which influence the expenditure of large amounts of money in recreation, reforestation, and engineering is also necessary. Whether this is done by the NWS, by contracting forecasters or by agency personnel will depend largely on availability of manpower and cost/benefit considerations. Logically, the NWS would appear to be the best source of this service. These are specialized services, and decisions need to be made on the extent of specialization which is justifiable.

At any rate, the meteorologists and the foresters are the building blocks to expand consciousness in applying meteorology to resource management. I suggest that the needs of the Department of Agriculture in forestry are broad-much broader than current operations would indicate. I also suggest that an expansion of the special forecast services offered by the NWS is necessary, and that forest managers and meteorologists both have a responsibility to expand these horizons.

Session II
Current Weather Forecasting Capabilities

Chairman: Jack S. Barrows, Professor
Department of Forest and Wood Sciences
Colorado State University
Fort Collins, Colorado

Current Capabilities in Prediction at the National Weather Service's National Meteorological Center¹

Edwin B. Fawcett^{2/}

Abstract.--The state-of-the-art in numerical weather prediction at the National Meteorological Center in Washington is reviewed. In particular, the use of fine-mesh models and their application to the prediction of precipitation, temperature and wind is described. Considerable progress has been made at NMC in the use of fine-mesh models during the last 5 years. NMC is also experimenting with the use of very-fine-mesh models to improve precipitation forecasting. In spite of this progress, there are still limitations to our overall skill in forecasting. The meteorologist in the NWS still plays an important role in evaluating and improving the numerical product. Important problems remain in application of numerical techniques to the forecasting of small-scale weather phenomena, such as thunderstorms and heavy precipitation.

INTRODUCTION

Operational numerical weather prediction began in the United States in 1954 with the organization in Washington, D. C. of the Joint Numerical Weather Prediction Unit, staffed by meteorologists from the Weather Bureau, Air Force, and Navy. The first operationally useful NWP forecasts were issued in the late 1950's, soon after the organization of the Weather Bureau's National Meteorological Center. The first operational NWP forecasts issued by NMC were based on a barotropic model, which covered most of the Northern Hemisphere (Cressman 1958). In 1962, a 3-level baroclinic model (Cressman 1963) suitable for operational use had been put into operation. Since 1966, a hemispheric 6-layer baroclinic model (Shuman and Hovermale 1968), which uses the primitive (Newtonian) equations (P.E.), has been used as the NMC operational model. A regional Limited-Area Fine-Mesh (LFM) model (Howcroft 1971) was added to the inventory of NMC's operational models in September 1971. The LFM, similar in design to the P.E. model, was

run to 24 hours until early 1976, when the program was expanded to run to 48 hours. The U. S. forecasting community now receives forecasts from the barotropic, hemispheric P.E. and regional LFM models twice each day, based on analyses made from 0000 and 1200 GMT observations.

This paper reviews the progress since 1955 in prognosis of synoptic-scale systems, and then discusses the application of NWP to the forecasting of specific weather parameters (e.g. temperature, precipitation, wind, etc.). The skill of some of these specific forecasts is also reviewed. Finally, results are shown from experimental precipitation forecasts with finer-mesh models, which are being developed for future use at NMC.

PROGNOSIS OF SYNOPTIC-SCALE SYSTEMS

The easiest way to begin a discussion of the current state-of-the-art in NWP is to review the progress in prognosis of the synoptic-scale systems which control the development and movement of the smaller-scale weather systems.

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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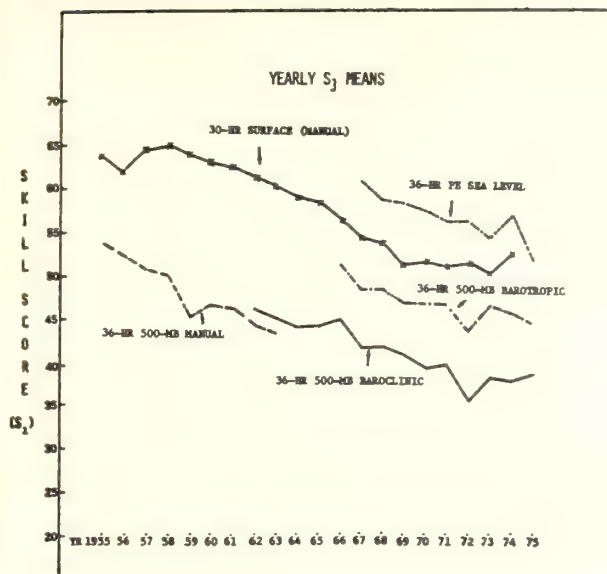


Figure 1.--Yearly mean S_1 scores for NMC's sea-level and 500-mb manual and NWP prognoses.

Figure 1 shows the skill score for twenty years of sea-level and 500-mb prognoses issued by the Weather Bureau's National Weather Analyses Center from 1955 to 1958, and by NMC since 1958. The score used is the S_1 score (Teweles and Wobus 1954) given by

$$S_1 = 100 \frac{\sum |e_G|}{\sum |G_L|}$$

where e_G = error of the forecast pressure (or height) difference, and

G_L = observed or forecast pressure (or height) difference, between grid points, whichever is largest.

The lower score is the more skillful. This score is sensitive to the distance between grid points (or stations) used in measuring the gradient errors. However, in the curves given in figure 1, consistent sets of grids have been used for verifying each prognosis, so that the improvements and differences in skill from year to year are real. Twenty years of experience with the S_1 score have shown the practical range between perfect and worthless progs to be 30 to 80 at sea-level and 20 to 70 at 500 mb.

Figure 1 illustrates the significant improvement in both sea-level and 500-mb prognoses since the introduction in 1958 of the operational 500-mb forecasts based on the barotropic model. Beginning about 1959, the skill of the manual sea-level prognoses improved, as more skillful and useful numerical prognoses became available. The improve-

ment in the skill of manual sea-level prognoses accelerated in 1966 after the introduction of the first useful sea-level prognoses from the 6-layer P.E. model.

Manual 500-mb prognoses were discontinued in 1962 after it became apparent that they were no more skillful than the 3-layer baroclinic 500-mb prognoses then available. The improvement in the skill of the 500-mb prognoses also accelerated in 1966 after the introduction of the P.E. model. It is interesting to note the consistent improvement (6 to 8 S_1 points) of the P.E. 500-mb prognoses over the barotropic prognoses during the 10 years of comparison.

Since 1971, use of the LFM model has further improved the numerical guidance available for operational forecasting. Table 1 shows mean S_1 scores for February through May 1976. The LFM prognoses at both sea-level and 500-mb are more skillful than the corresponding large-mesh progs, except at 12 hours over the western U.S.

Table 1.-- S_1 scores for large-mesh P.E. versus fine-mesh P.E. (LFM) over eastern and western U.S. (Feb. through May 1976)

	EAST OF DENVER			WEST OF DENVER		
	P.E.	LFM	P-L	P.E.	LFM	P-L
12 HR FCST S.L.	38.2	37.9	+0.3	42.1	42.5	-0.4
500-mb	21.5	16.3	+5.2	25.4	22.9	+2.5
24 HR FCST S.L.	45.8	43.5	+2.3	50.0	49.5	+0.5
500-mb	27.5	21.5	+6.0	31.9	29.5	+2.4
36 HR FCST S.L.	54.6	50.4	+4.2	58.3	56.8	+1.5
500-mb	34.3	28.6	+5.7	39.4	37.1	+2.3
48 HR FCST S.L.	63.9	59.0	+4.9	63.7	61.1	+2.6
500-mb	40.7	36.3	+4.4	44.8	43.4	+1.4

The improvement of the LFM over the P.E. increases with time at sea-level, where the use of a finer mesh improves the definition of smaller-scale systems. At 500-mb this improvement levels off and decreases after 24 hours due to the smoother less detailed 500-mb flow patterns observed and forecast. Table 1 also shows that both the large- and fine-mesh models are less skillful over the western U.S. Users of numerical guidance have noted this fact for many years. Failure to correctly model the

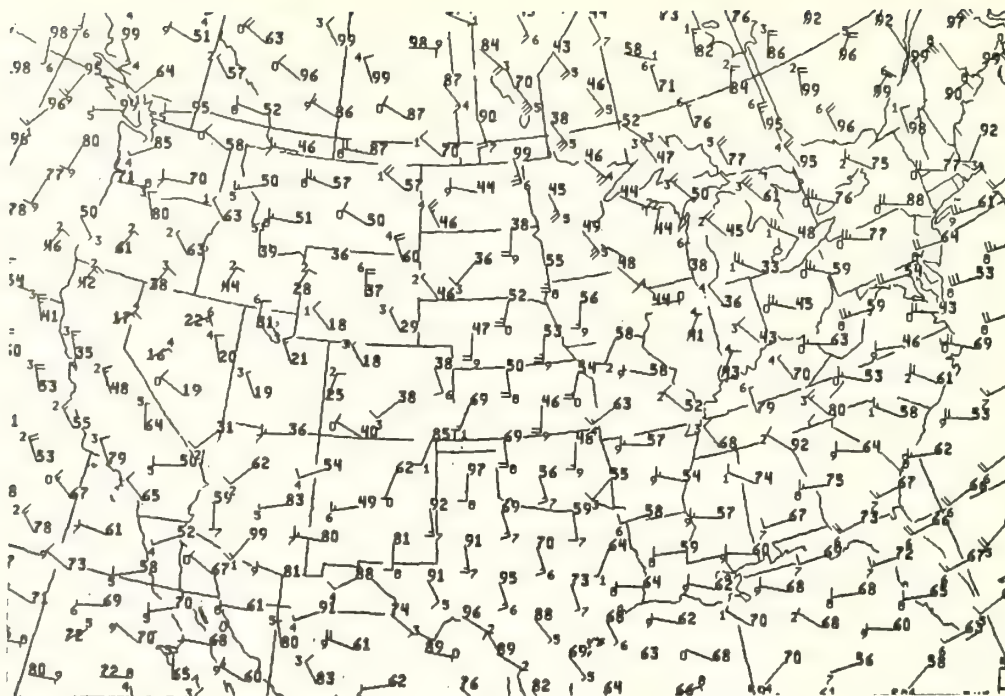


Figure 2.--Twelve-hour prognosis of boundary layer winds and mean relative humidity from NMC's regional (LFM) model, valid at 0000 GMT 13 July 1976.

details of the complicated terrain effects on the atmosphere and the absence of observations over the Pacific are suspected as causes for this difference in skill.

USE OF NWP IN FORECASTING WEATHER ELEMENTS

The increased skill which has been demonstrated in forecasting the evolution of synoptic-scale systems at sea-level and 500-mb illustrates only part of the story of progress in NWP. Use of winds and temperatures from NMC's P.E. model for flight planning has become very general among airlines and other aviation interests. Direct output of forecast parameters at U.S. cities (e.g., boundary-layer winds, layer humidities, vertical velocity and lifted index) from the LFM in bulletin form are available twice each day via request-reply from the FAA's weather switching center in Kansas City. These parameters are very useful to the forecaster in the prediction of precipitation. An example of the boundary-layer winds and humidities from the LFM as they are transmitted via facsimile, is shown in figure 2.

Another method of obtaining objective forecasts of local weather elements uses statistical methods to complement the output

of numerical prediction models. This is the Model Output Statistics (MOS) technique in which local observations of weather parameters are matched with output parameters from numerical models for a period of a year or more. Forecast equations are then derived by statistical techniques which can account for biases and inaccuracies in the numerical model and for local climatology. The MOS technique has been applied to forecasts of many weather elements including temperature, precipitation, winds, clouds and thunderstorms by the National Weather Service's Technique Development Laboratory (Klein and Glahn 1974), and are now an important part of NMC's daily operational products sent via facsimile and teletype.

The state-of-the-art in numerical forecasting of rainfall occurrence and amount, thunderstorms, etc. is difficult to specify because most numerical forecasts of these weather elements have only become available in the last two or three years. However, useful forecasts of maximum and minimum temperatures at individual U. S. cities have been provided from NMC's computers for several years. Figure 3 shows a record of verification of these forecasts from 1968 through 1975. The steady increase in skill during the 8-layer period can be attributed to several factors,

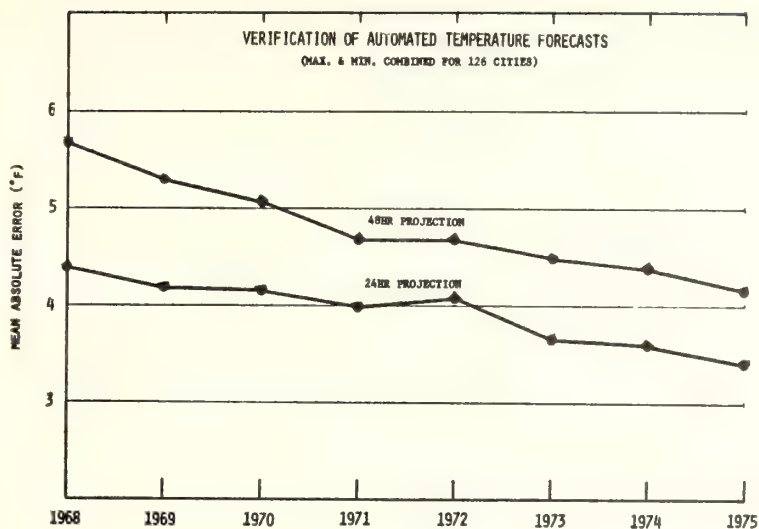


Figure 3.--Mean absolute errors of automated temperature forecasts (combined maximum and minimum) for 126 cities for the years 1968 through 1975.

such as increased skill of the P.E. model used to make the forecasts, rederivation of the equations with a larger data base, and introduction of the MOS technique in 1973.

Most weather forecasters would agree that temperature is one of the easiest weather elements to forecast. Precipitation, however, is one of the most difficult; and numerical forecasts of precipitation have been the least useful of all the output from numerical models. Weather forecasters still have to depend on personal skill and experience in interpretation of numerical guidance when making precipitation forecasts. This is particularly true for forecasts of precipitation amount. Figure 4 illustrates a ten-year record of verification at NMC in manual forecasting of areas of precipitation over the U.S.

There is some evidence of slight improvement in the 48-hour projections, but this record certainly shows less increase in skill with time than the temperature verification curves or the curves for sea-level and 500-mb prognoses. If one examines the annual variation in skill of the manual QPF, the reason for the low forecast skill becomes evident. Figure 5 shows the annual variation of the maximum, minimum and mean threat scores for 24-hour forecasts of one inch or more of precipitation. Note the seasonal variation in skill. This can easily be translated into a variation of skill with the predominant scale of precipitation systems—synoptic scale in the winter to meso (or smaller) scale in the summer. Forecasters know it's harder to forecast occurrence and distribution of precipitation with thunderstorms than with winter storms.

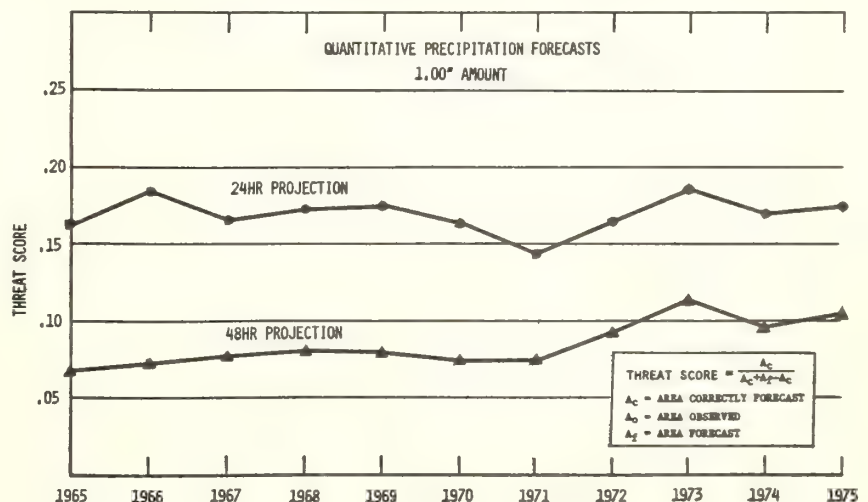


Figure 4.--Mean annual threat scores for 24-hour projections (top curve) and 48-hour projections (bottom curve) for areas of 1" or more of precipitation during a 24-hour period; manual forecasts by NMC's QPF Branch.

$$\text{THREAT SCORE} = \frac{A_c}{A_c + A_f - A_o}$$

A_c = AREA CORRECTLY FORECAST
 A_o = AREA OBSERVED
 A_f = AREA FORECAST

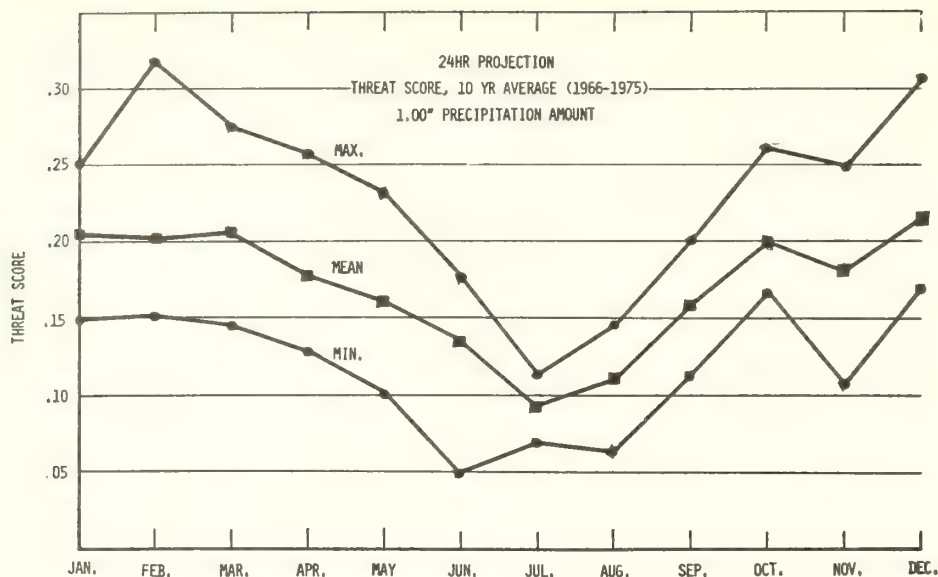


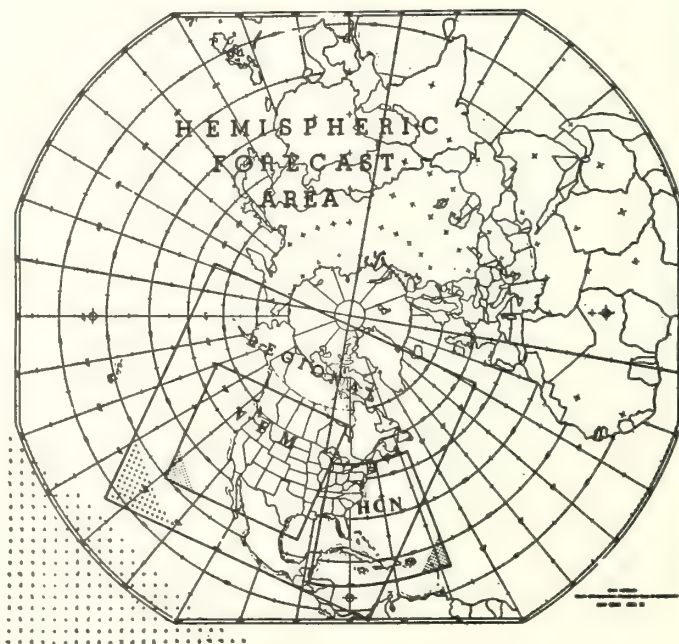
Figure 5.--Annual variation of the maximum, minimum and mean threat scores of the 24-hour projection of 1" or more of precipitation during a 24-hour period; manual forecasts by NMC's QPF Branch.

WHAT'S AHEAD IN NUMERICAL FORECASTING

One of the primary goals of NMC is improvement of operational numerical models, which hopefully will be reflected in improved forecasts to the public. Improvement of numerical precipitation forecasts is high on the list of tasks under this goal. Figure 6 summarizes the area and grid system used in some of NMC's operational and experimental models. Operational use of the LFM (regional) model on a 190 km grid has already shown improvement over the 6-layer hemispheric model on a 380 km grid.

Among experimental models now being developed at NMC, is one designed for forecasting the movement of hurricanes. The Hurricane model (Hovermale et al, 1975) normally operates on a 60 km grid and is designed to move with the storm being forecast; thus the name Movable Fine Mesh (MFM) has been applied to this model. Also, in the NMC inventory is a version of the Regional (LFM) model on a finer (95 km) grid. This is called the Very Fine Mesh (VFM) model.

Figure 6.--Grid areas for some of NMC's operational and experimental models. The spacing of grid-points with each model is shown in the triangle in the corner of each area.



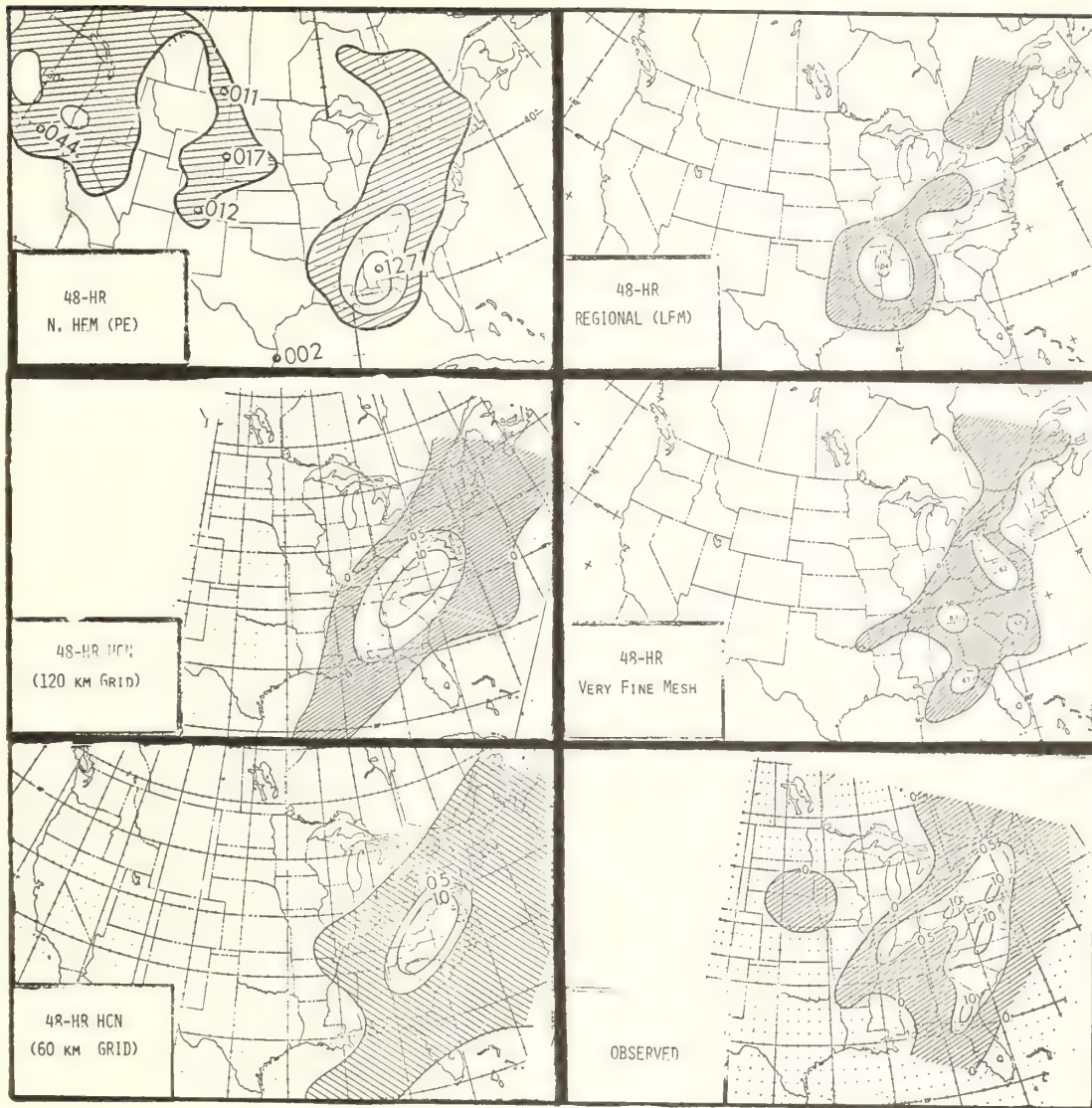


Figure 7.--Forty-eight hour forecasts of 12-hour precipitation from 0000 to 1200 GMT on 26 December 1975 made by 5 NMC operational and experiment models. The observed precipitation is in the lowest right-hand panel.

Several experiments have been run at NMC to find out what benefits can be realized from using finer-mesh models, particularly in precipitation forecasting. Figure 7 illustrates the results of one of these experiments: a 48-hour forecast of precipitation with last year's Christmas storm. This storm moved from the Gulf of Mexico northward to the Ohio Valley, deepened and produced significant precipitation both east and west of the Appalachians, as shown in the lowest right-hand panel of figure 7. Each of the 5 models used in this experiment are similar in basic structure;

the main difference is in the size of the grid used in each model. Note that the location of the heaviest precipitation area improves with each succeeding finer-mesh forecast beginning in the upper-left panel of the figure. This and other similar experiments indicate that use of a finer mesh increases the skill of the model in locating the area of heaviest synoptic-scale precipitation. Even the 60 km Hurricane model did not successfully forecast the smaller-scale detail in the precipitation pattern east of the Appalachians.

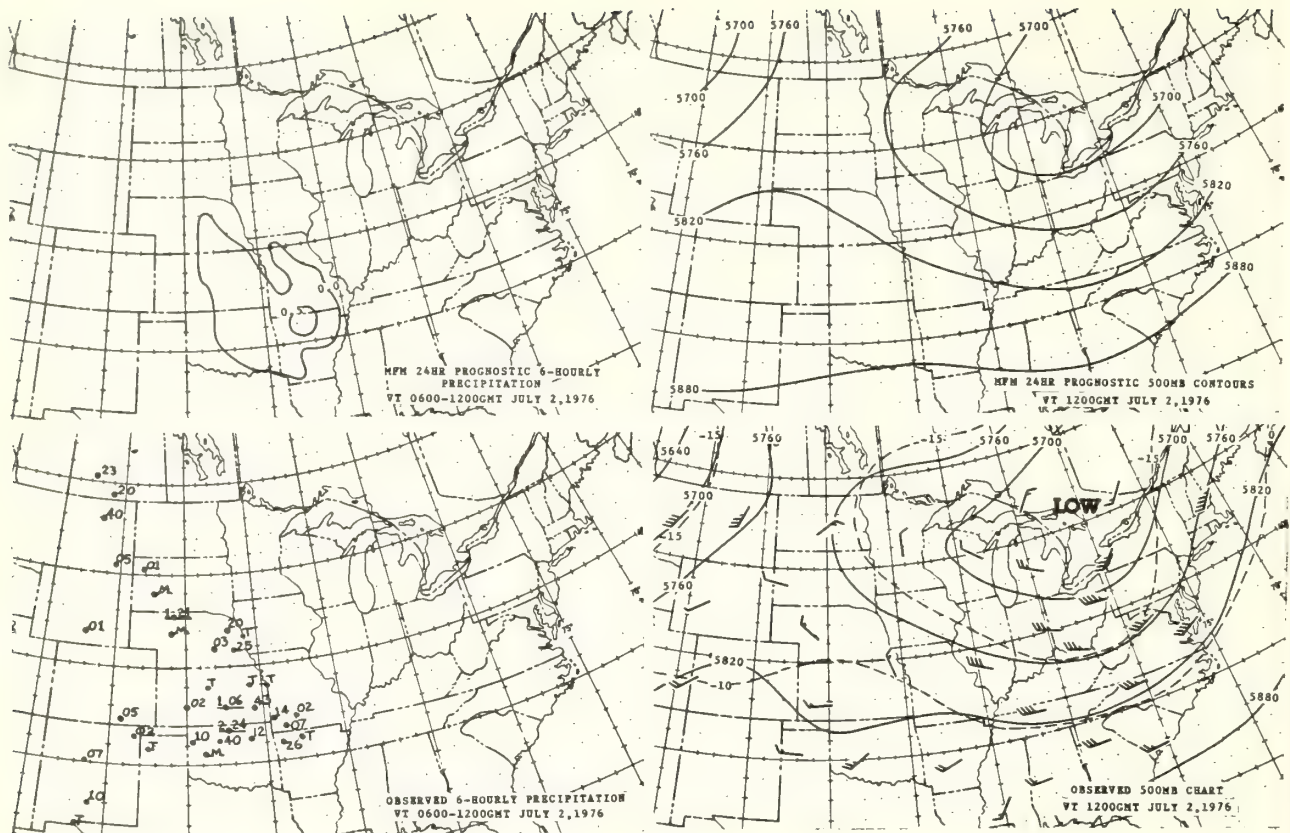


Figure 8.--Twenty-Four hour forecast of 6-hourly precipitation and 500-mb contours made by NMC's Movable Fine Mesh (Hurricane) model (top diagrams) and verification (bottom diagrams)

Experiments run with the 60 km Hurricane model on warm season situations tend to confirm that the model is not forecasting small-scale precipitation. Figure 8 illustrates this for a situation last July in which heavy convective precipitation occurred in the central Great Plains. The model underforecast the amounts of precipitation and located the area too far east. In fairness to the Hurricane model, it should be stated that both the hemispheric P.E. and regional LFM were unsuccessful in this case. Also, the current version of the Hurricane model does not provide for the diurnal heating cycle and has a convective scheme oriented toward maritime tropical conditions in contrast to the two larger mesh operational models.

CONCLUSIONS

Current capabilities in use of numerical prediction for forecasting can be summarized as follows:

- o Significant progress has been made in the

past 10 to 15 years in the forecasting by numerical methods of synoptic-scale weather features and of weather parameters which can be derived from them.

- o The progress in forecasting precipitation and other small-scale weather elements has been very small.

- o Finer-mesh numerical models already show some skill in improving forecasts of the location of precipitation areas and precipitation amounts.

- o Important problems remain to be solved in the application of numerical techniques to the forecasting of smaller-scale weather phenomena, such as thunderstorms and heavy precipitation.

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REFERENCES

- Cressman, G. P.
1958. Barotropic divergence and very long atmospheric waves. *Monthly Weather Review* 87:367-374
- Cressman, G. P.
1963. A three-level model suitable for daily numerical forecasting. Technical Memorandum No. 22, National Meteorological Center, Weather Bureau, Washington, D. C. 22 pp.
- Hovermale, J., Marks, D., Chu, R., Scolnik, S. and Jones, R.
1975. Experimental forecasts of hurricane movement with a limited-area fine-mesh grid. Paper presented at Ninth Technical Conference on Hurricanes and Tropical Meteorology, May 1975, Key Biscayne, Florida.
- Howcroft, J.
1971. Local forecast model: present status and preliminary verification. Office Note No. 50, National Meteorological Center, National Weather Service, Washington, D. C. 22 pp.
- Klein, W. H. and Glahn, H.R.
1974. Forecasting local weather by means of model output statistics. *Bulletin of the American Meteorological Society*. 55:1217-1227.
- Shuman, F. G. and Hovermale, J.B.
1968. An operational six-layer primitive equation model. *Journal of Applied Meteorology* 7:525-547.
- Teweles, W., Jr. and Wobus, H. B.
1954. Verification of Prognostic Charts. *Bulletin of the American Meteorological Society* 35:455-463.

Review of Operational Forecasting¹

William G. Sullivan^{2/}

A short review and discussion of operational fire weather forecasting from a field forecaster's point of view. Forecast problems, accuracy, and limitations imposed on the forecaster are discussed.

INTRODUCTION

Fire weather forecasting service has been available to land managers for many years but it was not until 1960 that an organized expansion plan was formulated and services increased throughout the country. Additional fire weather forecasters were assigned to many existing offices and new programs were established in areas where none had existed prior to that time. There was little change in the program from 1965 to the early 1970s as the new and increased programs were being developed. In the early 1970s a major forecast program reorganization was undertaken in the National Weather Service which affected some fire weather program services.

During this same period of time many changes occurred in the approach to forecasting itself. These changes were the result of new technology such as improved numerical modeling, satellite data, radar, and improved communications equipment.

The purpose of this paper is to discuss the present state of the art of fire weather forecasting in light of these changes and the impact of these changes on the fire weather programs and services.

FIRE WEATHER FORECASTS

In talking to fire weather users one often gains the impression that they think there is something basically different between fire weather forecasters and forecasters making other types of forecasts. This apparently stems from the user's failure to make the distinction between forecasting and services. They have a tendency to focus on the fire weather program as a whole. In this context you will often find that a user's opinion of the forecasts depends not so much on the quality of the forecasts as the personal relationship that exists between the user and the fire weather forecaster. One is not quick to criticize one's friends. On the other hand you will sometimes find the user's opinion of the forecasts to be quite low due to a lack of close working relationship between the user and the forecaster when, in fact, the forecasts are well up to the state of the art.

Fire weather forecasting per se, does not differ markedly from any other type of forecasting. We are trying to get from here (initial conditions) to there (conditions at some future time). Fire weather forecasters approach this task in the same manner as any other forecaster using the same basic tools and information.

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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The starting point for all forecasters is the basic guidance material disseminated by the National Meteorological Center (NMC) in the form of prognostic charts generated by the various numerical models in use by

the National Weather Service. During the past few years there has also been an increasing amount of objective guidance material obtained from statistical output of the numerical models (MOS). This output provides direct forecasts of temperature, probability of precipitation, wind, cloud cover, and other information not directly related to land manager's use. At the present time the MOS forecasts are provided only for cities but are useful in some fire weather areas through interpolation.

From a forecaster's point of view there has been a marked improvement in the operational numerical models in the past 10 years. This stems not only from more advanced models but from increased observational input such as that obtained from satellites over ocean areas. Evidence of this can be seen in a trend away from the development of local objective forecast schemes using observed data in favor of methods using input derived from the models. There has also been a trend toward using subjective evaluation of the model progs in place of some of the older objective systems. An older objective system for forecasting Santa Ana winds is a good example. Once the basic mechanism for the development of these winds were better understood, the improved numerical progs give a more reliable forecast than the objective system.

From the point of objective guidance received from the NMC the forecaster then goes to an almost purely subjective routine. Many offices have one or two local objective forecast systems to aid in the process but few, if any, use a system without subjective adaptation. The subjective process is an individual thing with forecasters but I like to think of it as a kind of mental modeling. In simplified terms, the forecaster models the current weather conditions with the current synoptic scale flow pattern and makes changes to these conditions as indicated by the progs and other guidance material using his or her skill in recognizing influences not known to the models. Where the state of the art ends and pure conjecture begins, I do not know.

Forecast Accuracy

In spite of the improvements in numerical modeling and additional data in former sparse data areas there has been only a small increase in accuracy of the day-to-day forecasts as shown by verification statistics. This can be misleading, however, because the major effort in forecast improve-

ment over the years has been in the forecast and dissemination of warnings of severe weather conditions and we have seen substantial improvement in this area.

The paradox of improved synoptic scale models with little increase in forecast accuracy stems mainly from the fact that it is a very long step from the synoptic scale progs to the weather forecast. Better progs permit the forecaster to start from a more sound base but local weather changes are most often the result of sub-synoptic scale systems, interaction between the flow and terrain, heat sources and sinks, and other energy exchanges either not handled well or not known to the model. A number of efforts have been, and are being, made to model the sub-synoptic scale in both predictive and diagnostic approaches and one could reasonably expect some increase in forecast accuracy from the results. Experience has taught us, however, that improvements occur in small increments and there is nothing to indicate that this will change.

Forecast Verification

It is always a risk to make statements about the accuracy of forecasts without supporting facts but verification data on fire weather forecasts are not all that abundant. There is no standard verification system for fire weather forecasts but most offices maintain some type of informal system as a check on their forecasts. Experience has taught us that verification is an important motivation in forecasting as well as in many other endeavors.

Those verification statistics that are available show average errors of 2 to 3 mph in wind speed and 5 to 8 percent in relative humidity forecasts. Errors in relative humidity are slightly larger in the northwest and eastern parts of the country. This is probably due to the higher average humidity in those areas rather than a difference in skill since errors are largest during periods of high humidity in all areas.

Some offices elect to verify one or more of the fire danger indices rather than weather elements but I believe this is falling into the same trap that users often do, i.e., looking upon NFDRS indices in absolute terms. It makes little sense to verify a weather forecast using some measure that includes input other than weather. I say this with the full knowledge that I have done the same thing in the past. Most of the indices in the NFDRS include the fuel

complex whose input is represented in a relatively crude sense.

Lynott and Graham (1973) made a comprehensive study of fire weather forecast verification for Washington and Oregon. Since they were studying an area with well established fire weather programs, in an area with a wide variety of weather and, for the most part, a group of experienced forecasters this study probably gives a good representative measure of fire weather forecasts for much of the country. The study included forecasts issued at six fire weather offices for both the morning and afternoon pre-suppression forecasts, although only the results of the 24-hour forecasts issued in the afternoon will be discussed here.

The results show that for the six stations the average error in humidity was less than 10 percent 67 percent of the time. The forecast wind speed error was less than 4 mph less than 83 percent of the time. These figures appear comparable to the average errors mentioned previously. I think it is safe to assume from this that the study is, on the whole, valid and probably represents the field forecasting level of the state of the art. Going further, the study also makes a distinction between the total number of forecasts verified and those cases where a large change occurred in the weather element. A large change was arbitrarily defined as a change greater than 9 percent humidity and greater than 3 mph in wind speed. A large change in humidity occurred in 36 percent of the cases and in wind speed 32 percent of the time. Of the cases with large changes the forecast humidity error was 9 percent or less 49 percent of the time and the wind speed error 4 mph or less 68 percent of the time.

Contrary to the conclusions indicated by the authors the results of their study show the forecasts to have a fairly high degree of usefulness in fire management. If we consider the magnitude of the forecast errors in the context of the NFDRS, for which these forecasts are intended, the value of the forecasts increases significantly. A change of 9 percent in relative humidity is roughly equivalent to a change of 1 percent in the fine fuel moisture. The error in wind speed has a much larger effect on the NFDRS but part of this effect is in the design of the system. If you allow the spread component to vary between 0 and 100 while restricting the wind speed to a range of 0 to 30 you are going to get large changes in the spread component with relatively small changes in wind speed.

We have no verification statistics for fire weather forecasts for other than pre-suppression forecasts, but since we continue to get a large number of requests for forecasts for going fires and prescribed burns it is safe to assume that these types of forecasts are very useful to land managers.

Limiting Factors

There are a number of factors that affect the accuracy of the forecasts that can be identified. The most important can be referred to as the fundamental limits imposed on the forecasts such as inadequate sampling of the atmosphere, imperfect modeling, and variations of the weather that are caused by sub-synoptic scale systems. These are limits imposed by the state of the art and are likely to remain with us for a long time to come. However, it is not necessary that these limits be eliminated in order to improve the accuracy of the forecasts. When we speak of inadequate sampling or imperfect models we do so in a relative sense. Perfection in either of these is probably unattainable but as we improve on the present state of the art we can expect some eventual improvement in the forecasts.

Ironically, one important factor that affects the forecasts is the unnecessary limits imposed on the forecaster by the users. This includes the time consuming job of preparing basically the same forecast in many different formats for the different users. The NFDRS in use by some of the larger fire control agencies requires a rather precise standard forecast format. There are many agencies throughout the country whose fire suppression programs do not require a system this sophisticated and therefore require forecasts in a variety of formats and sizes. Any time taken from the forecaster for this type of work is time that is not available in the formulation of the forecast. In addition, this work detracts greatly from the forecast during those periods of time when the fire weather specialist is not on duty and the forecasts are made by other forecasters. The decrease in quality of the forecast stems from other forecasters getting bogged down in detail rather than any difference in skill.

Other limits included in this are the requirement that forecasts be valid at a point in time rather than for average conditions, poor quality of observations, no observations at all in some areas during fire situations, and last but not least, AFFIRMS.

The problems with AFFIRMS has not changed significantly since it was reported on by Sullivan (1974). The main problem for the forecaster with AFFIRMS lies with the restrictions in the way forecasts can be entered. On the one hand it is desirable to keep the computer program small for economic reasons while on the other the forecaster needs to be able to enter precisely the forecast he wants for each station. Without this ability the accuracy of the forecast will suffer. During the 1975 fire season, WSFO Los Angeles, discontinued the routine practice of making special forecasts commands to overcome observational errors or nonrepresentative observations due to temporal variations in the weather. Our forecast error promptly increased but we have continued the policy anyway. At least one fire weather office in the west has discontinued their verification program because of these problems with the ZONE command in the AFFIRMS program.

Forecast Application

The limits on the accuracy of the forecasts notwithstanding, there is much value in the forecasts. How much value depends not only on the forecast but also the manner in which it is used. On the whole, it has been my experience that users expect more of the forecasts than it is possible for the forecaster to give and utilize very poorly that which is available. This may sound harsh but it is not meant to be. It is simply an observation whose validity can easily be shown but which I will not go into here. That it may be true, however, has and is being increasingly recognized by people concerned with this problem.

Two meetings held earlier in the year on the west coast discussed weather needs for fire and wildland managers. It was brought out in both meetings that weather information presently available could be better utilized. The second meeting, in touching on this subject, pointed out that meteorological results are transferred to people who are neither academically nor occupationally trained in meteorology. Actually, for most meteorological applications, the technology gap occurs a little further down the line. Meteorological research results are normally transferred to the forecasters who in turn pass the acquired knowledge to users as operational information. There are some climatological applications, of course, that can be passed directly to the user.

A large technology gap does exist, however, between the forecaster and fire and wildland user groups that prevents maximum utilization of weather information. It is not the local manager's fault because obviously people would prefer to be completely knowledgeable about whatever they have to do. We have taught fire managers some very elementary meteorology in fire schools, and somewhere along the way some have gained the impression that these people have a knowledge of meteorology sufficient for a wide range of applications. I do not think we will bridge this gap between forecast information and user application at the field level until applications people, academically and occupationally trained in meteorology, are included as a part of the user organization. This is especially true where the application of weather information is required in complicated and sophisticated land management systems such as the NFDRS.

FIRE WEATHER SERVICES

The NWS fire weather program provides a number of services in addition to the forecast program. The forecast reorganization of the NWS had some impact on these services but it is difficult to determine the exact extent because of several other factors that have also occurred in the past few years.

From my own personal experience, commitments to other NWS programs imposed on the fire weather forecasters did not, in themselves, restrict or decrease the service provided to fire and wildland user agencies. What it, and other work schedule commitments, did was to limit the instant accessibility of the fire weather forecaster by the users. The solution to this problem is better planning on the local level in connection with those services other than forecasts, such as consultation, training, etc.

Mobile Units

Fire weather mobile units manned by a fire weather forecaster are available for large going fires and prescribed burns throughout most of the western states. Coverage is quite extensive and units are moved from district to district when required during large and multiple fire situations. These units have proved invaluable in the west where terrain influences on the weather are very large. The mobile units are replaced and equipment

upgraded from time to time to maintain their effectiveness.

Consultation With Users

Another service provided over the years has been local consultation with users on fire and wildland management problems. A great deal of the application of weather information during the past has been accomplished on the local level by the forecaster and user. This is one of the more personalized services provided over the years, but rarely has this phase of fire and wildland management been exploited to its fullest potential because of its dependence on personal relations, lack of organized program and direction, and time limitations on both sides.

Training

Fire weather forecasters serve as instructors at fire behavior schools at the request of various fire control agencies. They have also been of great help in formulating standard training courses for the U.S. Forest Service and Bureau of Land Management. Most training schools are planned far in advance so the fire weather forecaster usually has no difficulty in eliminating conflicts with other program commitments when requested to participate. Some local fire school participation is still requested on relatively short notice, however, and more advanced planning with the forecaster will be required in these cases.

Weather Station Inspection

This service has consumed a good portion of the forecaster's time during the pre-fire season, however, during the past few years this has been drastically reduced due to budgetary restrictions. From a personal standpoint I think this is a case where evolution in the program would have accomplished the same effect. The location,

installation, and routine inspection of fire weather stations can easily be handled by user personnel with a small amount of training.

SUMMARY

The NWS provides fire weather services over a wide range of activities with the main one being the extensive fire weather forecasts for fire and wildland management.

The forecasts are, in general, well up to the state of the art and provide a useful and necessary service to user agencies. The forecasts contain technical information valuable to the users but which require more technological knowledge within the user agency to obtain the full benefit of this information.

There are certain limiting factors that affect the accuracy of the forecasts, some of which are imposed by the state of the art and whose effects can only be reduced slowly. Other limiting factors are often the result of user demands and application, and can be reduced significantly with a minimum of effort. Research is needed in all areas but a strong research program directed toward applications offers the quickest rewards.

Effects of the NWS forecast reorganization has had some effect on services but they are difficult to define. Where adverse effects have occurred they should be examined and solutions sought.

REFERENCES

- Lynott, Robert E., and Howard E. Graham.
1973. An Evaluation of Fire-Weather Forecasts in Oregon and Washington in 1971 and 1972.
- Sullivan, William G., Jr.,
1974. Problems in Forecasting for the National Fire Danger Rating System and AFFIRMS.

A Review of National Weather Service Policy on Services¹

Gerald A. Petersen^{2/}

Abstract--The basic National Weather Service policy on services is still to meet the objectives of the service programs by the most efficient use of resources and technology. The present operational policy is to concentrate our professional talent in large Weather Service Forecast Offices.

The National Weather Service has a history of serving the needs of forestry that extends back to 1913. During this 63 year period, advances in technology, the state of the art, availability of professional staffing stated needs of forestry weather users, and the vagaries of budgets have caused many changes in the way we have provided forestry weather services. Over the years, our policy has been to meet the objectives of the Fire Weather Program by the most efficient utilization of available resources and technology; and to insure that any changes in our operating procedures did not degrade the service level. Our present method of meeting program objectives makes use of the facilities and staffs of our larger offices to provide the required fire weather service. These larger offices, termed Weather Service Forecast Offices, have relatively large professional staffs and are the first to receive new technological equipment. By concentrating forecasters and equipment in 52 Forecast Offices, we can make the best use of professional talent, modern technology and the state of the art advances to meet the weather support requirements of all of our "customers." Over half of our Forecast Offices do have an extra forecaster assigned to the staff as a Fire Weather Focal Point; the remainder of the Forecast Offices use their regular staff to provide their assigned Fire Weather Services.

In addition to the Fire Weather support provided by the Forecast Offices, 15 smaller Weather Service Offices, mainly in the Western U. S., are especially staffed to provide Fire Weather Service. In the Far West, on-site support also is provided by mobil fire weather units.

Of course, local forecasts and advisories on local weather conditions are available to Forestry interests at most of our 249 Weather Service Offices throughout the country.

One aspect of the present NWS Special Program operation that has raised "problems" among some of our old-line forecasters as well as among some of our "customers", is what we call the Focal Point/cross-utilization concept and what some of you term the "Problem of the Faceless Forecaster." NWS implemented cross-utilization to meet the tremendous and ever-increasing need for weather services of all types. In the case of Forestry weather, expanded, sophisticated land management and fire suppression operations have vastly increased the demand for special weather support. This demand has grown to the point where, in most cases, a single meteorologist in an office, working 8 hours per day, 5 days a week, 48 weeks a year cannot possibly satisfy the need. In our view, the most efficient way to meet the operational weather needs of forestry interests is to cross-utilize our forecasters and tap the abilities of several "Faceless Forecasters."

This "Faceless Forecaster Problem" is really psychological and should have no real impact upon the quality of our operational services. Once the special program user--in this case the forestry community--recognizes that trust can be placed in this different mode of operation, the psychological impact will diminish. The "faceless forecaster" has long been serving the needs of public weather, flood forecasting, and severe weather warning, as well as many other specialized interests such as those involving aviation, marine shipping, and recreation. So long as our forecasters are kept aware of the weather needs of the forestry interest, we are sure that we can fulfill the important requirements of operational forestry weather support. And that really is one of the reasons why we have meetings of this type from time to time.

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One of our greatest problems with cross-utilization is dealing with misconceptions of what cross-utilization does. One common misconception is: "Under cross-utilization, there's no fire weather support available from an office when the fire weather man is working different shifts." This simply is not true; other members of that office's forecast staff can and do provide operational fire weather support. In fact, cross-utilization provides the depth of manpower to provide those important operational services on an around-the-clock, 7 day a week basis if needed, regardless of sickness or health, days off, or vacation plans of any one man.

Another misconception is: "cross-utilization has replaced trained fire weather forecasters with untrained ones." This is really a half-misconception. Trained fire weather forecasters have been replaced with untrained fire weather focal points, but this is not the fault of cross-utilization; it would have happened no matter what. Our trained people retired or were promoted to other jobs. We are now taking steps to develop training plans for the fire weather, agriculture, and marine programs. A small beginning was made this past September when we sponsored two consecutive seminars for our Eastern fire weather focal points.

All in all, the cross-utilization concept does provide more depth to our services, especially to the special program forecast services and does permit greater opportunity for career development to the Special Program meteorologist.

For those of you who yearn for the "Good Old Days", a study of Fire Weather Forecast verification in 1929 found that the second period Relative Humidity forecasts were so bad that it was recommended that that part of the forecast be dropped. Since that time I believe we have been able to make at least some improvement in the second period forecast.

While our 1929 Forecaster was plagued with sparsity of information and spent much of his time trying to figure out what was happening, our modern forecaster may, at times, be overwhelmed with data, information, and guidance, but he does spend most of his time working on the forecast problem.

To produce the products to meet the requirements of the Fire Weather Program,

our forecasters have the following material available on a 24-hour, 7 day a week basis:

- Extensive forecast guidance material from the National Meteorological Center, produced by both computer and man. While the NMC products may not be specifically designed for Fire Weather, they can be adapted for Forestry Weather use.
- Plotted and analyzed charts. Forecasters only do minor supplemental plotting and analysis.
- Data from several observational networks. This data includes hourly surface weather and radar reports along with upper air observations.
- Satellite photos and interpretive discussions. All Forecast offices do receive photos of their area as frequently as every 30 minutes on a day and night basis. Special satellite photo interpretations are provided for our forecasters from Satellite Field Service stations at Miami, Washington, Kansas City, and San Francisco.

Soon the forecaster may have even more NWS resources to draw upon. The NWS and the U. S. Forest Service are exploring the feasibility of adding a forestry weather function to our Environmental Study Service Centers. An E.S.S.C. forestry operation could support our fire weather forecasters by acting as a liaison between the user and producer, by identifying problem areas, and by providing specialized weather products that would supplement our regular forestry weather forecasts.

So much for the present operations of the Forestry Weather program. What's the outlook for NWS Special Program Services over the next 5 to 10 years? Frankly, we can't ever be too sure. However, after the turbulence resulting from the implementation of AUTOMATED FIELD OPERATIONS AND SERVICES (AFOS) program subsidies and new automated data handling support become operational, we believe more forecaster time and attention will be available for all of the Special Programs. We don't really see any major changes in the National Weather Service policy for Forestry Weather Services. Simply stated, "The NWS will do what it does best to help Forestry interests to do what they do best."

Adaptation of Meteorological Products for Specific Forestry Uses¹

Paul E. Krauss^{2/}

ABSTRACT--A brief review of the primary uses of meteorological products by the forest protection organizations in the Pacific Northwest. This information relates closely to the activities and responsibilities of the Department of Natural Resources in the State of Washington and its use of meteorological information.

The title of this assignment has bothered me! Adaption seems to say I have purchased a new shelf item which I must now find a way to fit to my needs. I am sure the subject heading was not intended to imply such a feeling, but I think it states very well an underlying problem today. In explaining my concern I will need to talk for a few minutes about the forest manager, one of the users.

The forest manager is requesting, yes, shouting for help. He is in a fixed location with specific acreage to manage primarily for the production of a wood product. He is faced with environmental problems imposed by nature itself and recently magnified by public concern to a point where his daily activities are monitored by the public. He must protect such things as air quality, water quality, aesthetics, soil productivity and the resource values he intends to market. He needs to know what's going to happen on his acreage today while he is engaged in executing his planned management program. He must know what impact that activity will have on the environment this evening, tomorrow, next month, next fall, and the years to come. Meteorology is a science! How often have you also heard or said that scientists talk among themselves? Now you're saying to yourself, ah ha--but he is wrong about meteorologists. But am I?

Meteorologists have used acronyms for a long time and these have quickly found their way, mixed with others relating to the forest managers' interests, into the current topics until they sound like the title to foreign manuscripts. The forest manager gets information from NOAA, OSHA, WISHA, FOCUS, BIFC, AFFIRMS, NFDRS, and FIRESCOPE to name those in use on

the West Coast. Meteorological information is transmitted by radio, telephone, teletype and computer and in that process is supposed to be decoded for the simplest of uses. The user gets a narrative which includes words intended to aid in the explanation such as diffusion, dispersion, inversion, stable, unstable, 500 and 800 millibar, intermittent, marine push, and thermal trough.

We have a meteorological research group in the Pacific Northwest who are quick to state that meteorological research up to 1969 was phenomena-oriented to such subjects as low level jet stream, sea breeze, smog transport, etc. Now it is to be expanded to solving problems for the western forest user in all aspects of forest meteorology. A word of caution, are these researchers agreeing among themselves again? The object of producing a product is to have it be sellable. Researchers must satisfy a need. In the Northwest the response by users or potential users to the inquiries by researchers has not been one of overwhelming enthusiasm. We must not ignore the replies that indicate the first priority is to be able to use what is available, or to understand the present state of the art.

Let us look at another type of research being applied by the forest manager. Silvicultural research people are conducting research for people practicing silviculture. The recipients of the research are persons who have been academically, as well as occupationally trained in silviculture. Contrast that with the background of the meteorologist doing meteorological research and the forester engaged in forest management. I think there is a technology gap that may be much wider between the meteorologist and the forest manager than that of which we are aware or wish to acknowledge and it can quickly expand from the present threshold. I want to illuminate that point because I think we all need to work toward the elimination or prevention of a technology gap. We must make sure the research results are made operational. We have already

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heard today about some of the needs of the user and the capabilities of the producer. Let's be sure that the capabilities and the research objectives initiated to satisfy the new needs are put together in a manner that will satisfy operational usefulness. Let's not produce a shelf item which requires some adaption by the user. Egotism has sometimes been defined as that certain something that makes a person in a rut think he is in a groove. Don't outrun your user. Accelerating technology is creating more variables than existed before. Are the intended users ready for the change? Good personnel management techniques must be applied by the user. It's too easy to say, "If you're so clever, why don't you give me some answers?" Currently meteorologists do give the user a minimum of a 24-hour glimpse into the future. Yet many recipients still wait until tomorrow to plan the day. Why? What is the nature of your audience? Think of other professions and their reaction if they could see tomorrow's paper 24 hours in advance. An investor would have difficulty waiting for the stock market to open. Personnel problems would be prevented. Production would be at maximum capacity. We involved in forest management must reassess our use of the available meteorological information and perhaps more important, we must clearly identify the needs not yet answered.

Well, what are the forest managers in the Northwest doing to utilize the present products of meteorology? I earlier said that the manager is interested in producing a wood product that is sellable. You are all aware of the success of the timber industry in the Northwest, but this action produces a by-product--slash, which has no market and presents a fire hazard as well as a problem in getting the land back into production. The forest manager prescribes a method of removal or reduction of the slash to solve these problems. Prescribed burning is often the solution. Imagine for a moment the concerns of escaped fire and damages to the soil which might occur if you choose the wrong time to burn an accumulation of up to 150 tons per acre of slash within the confines of the forest. This decision to burn requires a careful study of known and predicted weather. Fuel moisture, the amount of moisture in dead wood is recorded for days since it is somewhat progressive and responds to rainfall and drying, either by sun or wind. Fuel moisture in the adjacent forest cover is studied to be sure a fire won't race through your natural barrier. Slope, aspect, elevation and geographical location are provided the fire weather forecaster. Readings of wind speed and its direction, temperature and humidity at specific times are also noted and a

spot forecast is made for the location. This forecast is the major tool used in the final decision to ignite. The 24 hour glimpse into the future has been used in the management decision.

Both the State of Oregon and the State of Washington have a smoke management program. This program is utilized to insure proper dispersal of smoke from, not only the prescribed burning, but for all the smoke occurring from forest land activities. The plan requires that all smoke gets above a 2,000 foot elevation over designated population densities and further it must meet the requirements of the Department of Ecology in the State of Washington who has the responsibility for carrying out the requirements of the Clean Air Act. Although this may not be a tool used by the forest manager, it is certainly a restraint under which he must daily do business. A smoke management forecast is required by the user.

In the State of Washington, the smoke management program is administered by the Department of Natural Resources. We request a prediction of wind activity at the 3,000 foot and 5,000 foot elevations. We need to know if it is stable or moving and its direction and speed. We plot the predicted routes of the smoke, and we know that it will travel 60 to 100 miles at a minimum. We study the fluctuations in temperature predicted for the day. Smoke rises higher with rapid heating. It correspondingly falls quicker on a cool day. If it appears that it will travel over designated areas, at too low an elevation, we inform the user that he cannot ignite due to smoke management problems.

The method of ignition is very important in reaching the decision to burn. We, involved in prescribed burning in the Northwest are using mass ignition techniques such as explosives to literally shoot the smoke to the desired altitudes for proper dispersal. In the past two years the logging industry and the Department have had considerable success by using a helicopter and a large drip torch suspended beneath the aircraft for quick ignition. I know of one instance this summer where 300 acres were ignited in 26 minutes by the use of two helicopters lighting in strips approximately 30 feet in width. This rapid ignition creates its own firestorm and the resulting draft drives the smoke to the desired elevation. The forest land manager is also becoming concerned about visibility and who will see the smoke. As a user, he needs to know more about smoke dispersal and where it might accumulate. Accumulation seems to vary from drainage to drainage. We need to have predictions for some of the major drain-

ages in the State of Washington.

Weather Forecasters are utilized in compiling the severity of our forest fire danger. The forecasts of weather combined with the National Fire Danger Rating System (NRDRS) provides us with the predicted fire danger level. The information predicted for temperature, humidity, precipitation, wind direction and wind speed are entered into the NRDRS, which generates some useful components and indexes when combined with a fuel type and slope. A few of the components of fire danger and indexes available are ones that predict the rate of spread, the probability of ignition, the resistance to control and the energy release. Each forest protection unit's daily activities are based upon the predicted fire danger. The strength of force for the next day for fire suppression and detection techniques are an indirect result of the fire weather forecast. For example, the ignition component is used directly for our air detection flights over the eight million acres of land we protect in Western Washington. The number of air detection flights per day and the time of the flights change from day to day as the predicted probability of ignition changes. The variation is from no flights to a maximum of three airplanes in the air on each of the six pre-planned flight paths.

This same information, the prediction of the fire severity, is also reviewed in considering the implementation of regulatory measures for forest users. In the State of Washington, and Oregon has similar statutes, we have the authority to partially restrict the industrial user to periods of the day in which he can utilize power driven spark emitting equipment to a point of total restriction or shutdown. Another user, the recreationist can also be restricted by a similar procedure. In that action a forest closure is enacted. In both considerations the mathematical probability of a fire starting, its predicted rate of spread and resistance to control in specific fuel modules are extracted from the known weather and the known action of fire in the fuels being considered are the tools used in making the decision. This provides us with a means of regulation in a specific weather zone or zones without involving the remainder of the state.

In the event of an extra period fire, the fire weather information is utilized in planning fire suppression strategy. This type of fire becomes a identity of its own, requiring forecasting for its specific geographical conditions and fuels. Mobile weather stations are utilized and we immediately build useful data to aid in both mobilization of forces necessary for sup-

pression and when that need is satisfied, a orderly demobilization plan is enacted from the continuing weather data.

The State of Washington has over 13,500 bits of weather information computerized for the year of 1975 on nine different weather zones. This information will lend itself to every kind of analysis desired in comparing predicted weather to actual and predicted manning schedules to what actually was used to further increase the creditability of fire planning for all types of forest activities and certainly for fire suppression needs. I have a real interest in the program of combining the computerized weather information with the fuel type, its density and age, the drought condition, the slope, elevation, aspect and other conditions of the fuel and topography to predict by map printout the progress of a known fire by time periods of the day if suppression action is taken. Not only would this be vital and useable tool in suppression work, but it would be a factor in determining which fire to take first action on in a multiple fire situation such as those resulting from a widely dispersed lightning storm. We utilize the weather data as a triggering device for fire prevention news and educational releases to the media. Many summer days on the west coast begin with overcast skies due to the marine flow of air from the coast. This lulls the citizen into a false sense of security as cool air, something you feel, is a poor indicator of the possible conditions of the forest fuels.

In Washington, our department has a working arrangement with the logging industry and other users of aerial photos by which the department contracts the aerial photography flights on a regular agreed time table and all users pay a use fee for photos used. We not only use the weather predictions for clarity of day since clouds cast shadows on the forest canopy and prevent clear photography but we also study the measured snow pack, which by reflection can overexpose the photo. Clear, shadowfree, non-glare aerial photography is the result of good weather information.

Wind direction and intensity is carefully reviewed for aerial spraying and fertilization contracts. You may have heard about the Spruce Budworm infestation in the western states, particularly Washington. Once agreement had been reached to spray, the spray had to be applied during the larva stage which is something less than 4 weeks. The progress from egg to larva is determined by the increase in temperature of the habitat area as we progressed from spring to summer. This narrow band of time was further restricted by the constraints involved in the use of aircraft. The daily

wind direction and intensity has a direct effect on the success of any spray application. The application of Dinitro, a chemical utilized to brown or dehydrate the foliage of broad leaf species so that it might be burned by prescription is done by utilizing the prediction for moisture free days along with the intensity and direction of wind for accurate spot application. The fact that you may want to rid your stand of broad leaf species for the purpose of propagating a coniferous forest may not be true of your neighbor, who is more interested in aesthetics. We need more weather information for spot locations for fertilization, dormat and foliar spray and aerial seeding. Wind draft is the most feared possibility. Night flying of helicopters by use of night vision goggles is a probability in the near future. Small drone aircraft are on the list of products available for the forest user to scan or oversee activities in the forest. Both of these uses will put an added demand on weather needs in the form of predicted air temperature, air densities, wind direction and intensity!

In land management work, forest landowners have just scratched the surface in utilizing

daily weather as a factor in work planning. I have explained the uses primarily related to fire activities and aerial work. Consider tree planting where one can utilize the knowledge of frost level information, freezing elevations and snow cover as well as knowledge of drying winds. We have begun to utilize weather forecasts to predict rain occurrence and intensity when involved in a road paving and oiling projects. After completion, we utilize it as a "Road Resource" alert when knowledge of heavy rains is predicted. This involves culvert patrol for cleanout and the placing of visqueen on recent cuts and fills to prevent damage and erosion. When aircraft are involved for the transportation link for V.P. tours, we again run to the forecast.

I think I should close with the recommendation that users and producers consider a "dial-a-forecast" for the future for the specific area of concern. Computerized output for a specific geographical unit predicted from a continuous input from automated weather stations is the desire. That ladies and gentlemen is the utopia the user desires for his acre today.

A Lightning Direction-Finding System for Forest Fire Detection¹

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Abstract.--A new type of lightning direction-finding system is described which detects primarily discharges to ground and which discriminates against intracloud discharges and background noise. Ground discharges are selected by requiring the wideband magnetic waveforms to have rise times, widths, and multiple peaks characteristic of return strokes. Other signals are rejected if they do not have the proper shape. Accurate azimuths are obtained by sampling the magnetic field just after the initial radiation field peak. Tests in Alaska and Arizona indicate the system accepts return strokes with efficiencies ranging from 70 to 90% and rejects 97% or more of the improper waveforms. Six systems have been operated in interior Alaska by non-technical personnel and have provided significant aid in the detection of lightning-caused fires.

INTRODUCTION

Each year lightning starts approximately 10,000 forest fires in the United States. The lightning fire hazard is particularly serious in remote areas, such as interior Alaska, because of the greater difficulty in detecting such fires quickly. Meteorological satellites and weather radars can identify convective cloud systems and precipitation, but not lightning. Large clouds may produce much precipitation and little lightning, and small clouds may produce much lightning and little precipitation. Clearly, an inexpensive electronic system which can automatically detect and locate lightning, partic-

ularly discharges to ground, over rather large areas with good accuracy would be a valuable aid to both fire management and fire weather personnel.

We should recall that a typical lightning discharge to ground or *flash* is made up of several component *strokes* (Uman 1969). A flash starts with a faint leader which proceeds rather slowly from cloud to ground in a series of short luminous steps. After this *stepped leader* contacts the ground, a very energetic and bright *return stroke* propagates up the ionized path established by the leader. After a pause of 30-50 milliseconds, a new leader, the *dart leader*, proceeds uniformly from cloud to ground and is followed by another bright return stroke propagating rapidly upward. A typical flash is made up of 3 or 4 leader-return stroke combinations. Return strokes have large peak currents, typically 20,000-40,000 amperes, which rise from zero to peak in just one or two millionths of a second while the strokes are still close to the ground.

In this note, we describe a new type of lightning direction-finding system which senses the magnetic fields which are produced by the large return-stroke currents. The system selects ground discharges by requiring

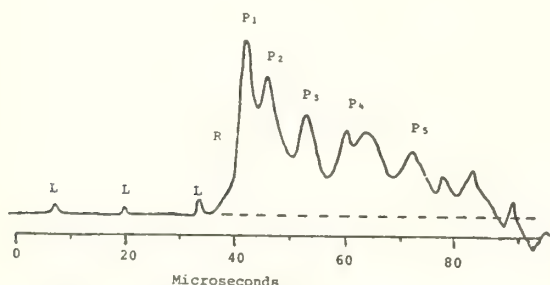
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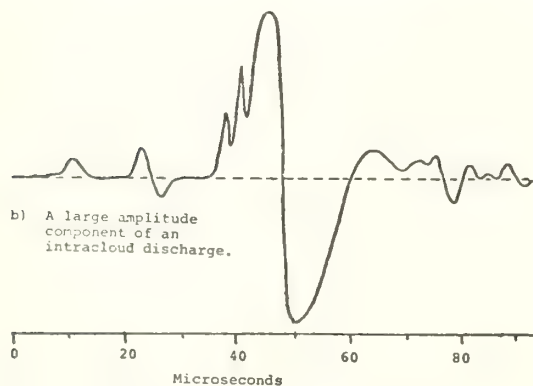
³/ Senior Engineer, Office of Scientific Systems Development, Denver, Colorado 80225 and Detection Specialist, Division of Fire Management, Fairbanks, Alaska 99703, respectively, U.S. Department of the Interior, Bureau of Land Management.

the magnetic fields to have rise times, widths, and multiple peak structures characteristic of return strokes. Intracloud discharges and background noise pulses are rejected if they do not have the proper shape. Accurate bearing angles are obtained by sampling the magnetic field just after the initial radiation field peak (Krider et al. 1976; Herrman et al. 1976). At the time of the peak magnetic field, the return stroke current is still close to the ground where the channel is nearly vertical and there are no large branches which produce magnetic polarization errors.

Figure 1a shows the shape of the magnetic field produced by a typical first return stroke in a lightning discharge to ground.



a) The first return stroke in a discharge to ground.



b) A large amplitude component of an intracloud discharge.

Fig. 1: Typical Lightning Magnetic Field Waveforms.

The large abrupt transition marked R is due to the onset of the return-stroke current, and the small L pulses preceding this are due to the stepped leader (Krider and Radda 1975). After the first large peak, P_1 , there are several subsidiary peaks, P_2 , P_3 , etc., which are probably due to branch currents (Krider and Weidman 1976). The magnetic waveforms produced by subsequent return

strokes in a flash are similar to figure 1a, except that the large subsidiary peaks are usually absent. Extensive studies of lightning in Florida and Arizona (Tiller et al. 1976) indicate that 99% or more of the return strokes which produce waveforms like that in figure 1 also transfer negative charge to ground, and thus the polarity of the magnetic field is well-defined.

Figure 1b shows a sketch of the field shape which might be produced by a large-amplitude intracloud discharge. Intracloud discharges occur about twice as often as ground discharges, and very often discharges to ground also have extensive intracloud components. Waveforms such as that in figure 1b may occur individually or in a series of rapid pulses and must be rejected by any system designed to detect only ground discharges. It should be noted that the overall rise time of the pulse in figure 1b is slower than that in figure 1a and that the pulse width is narrower.

APPARATUS

The lightning direction-finding system is shown schematically in figure 2 and consists of a wideband antenna, a pair of 7 m^2 -turn vertical loops oriented north-south and east-west (see fig. 3); high- and low-gain signal processing electronics for a wide range of sensitivity; an x-y plotter to record lightning azimuth vectors; and a microprocessor to digitize the data and type the results on a teletype. The antenna system is very similar to that described by Krider and Nogge (1975). The electronics are functionally quite similar to those described by Krider et al. (1976), except for improvements in the pulse-shape selection circuits. As we shall see, magnetic fields are accepted if they have rise times, widths, and multiple peaks similar to those in figure 1a and are rejected if they have shapes similar to figure 1b.

In the processing electronics, the output of each antenna loop is amplified and goes to a track-and-hold circuit. The two outputs are also full-wave rectified and summed to provide a direction-independent signal for use in pulse-shape selection. The summed signal is differentiated to determine the time of the first large peak in the waveform, and if this peak occurs within the proper time interval, the NS and EW voltages are held in the track-and-hold circuits. If the pulse-shape circuits verify that the remaining signal satisfies the shape criteria in all other respects, an output is generated

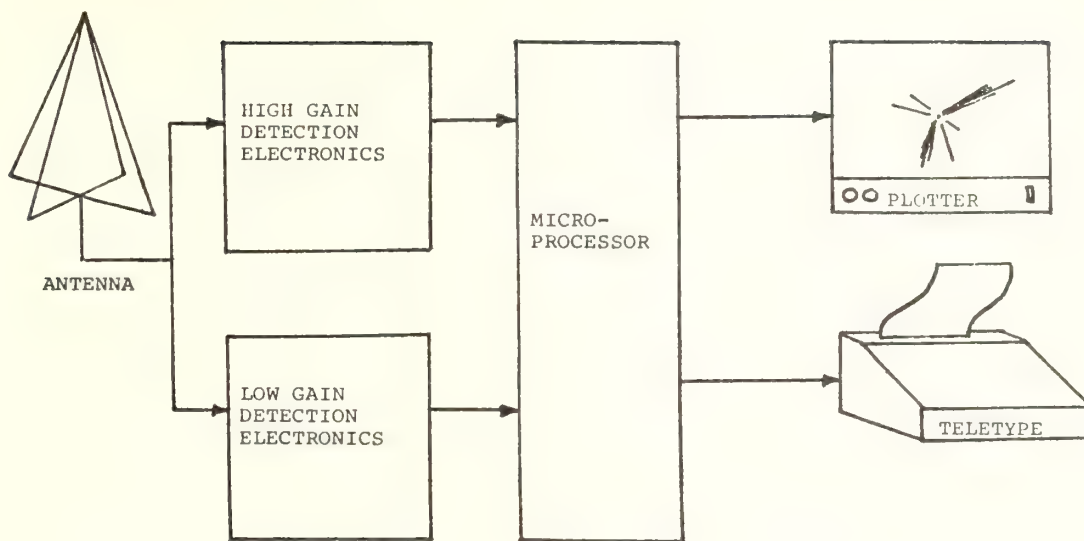


Fig. 2: Block Diagram of the Lightning Direction-Finding System.



Fig. 3--Photograph of the direction-finder antenna at Fairbanks, Alaska.

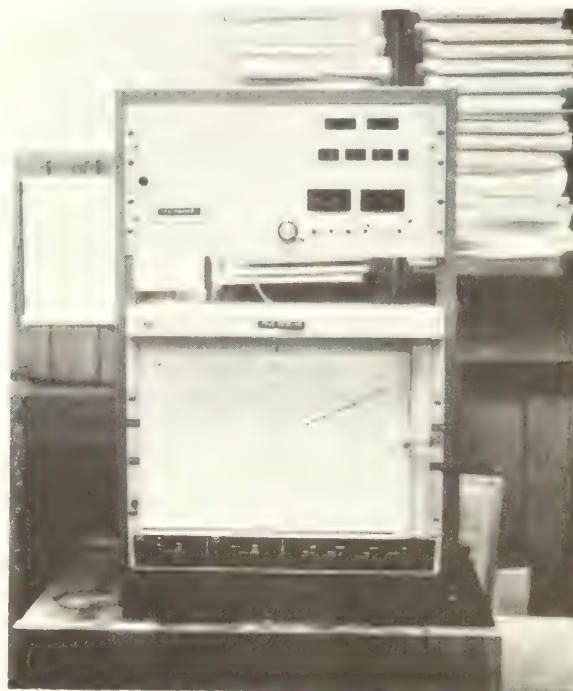


Fig. 4--Photograph of the system electronics and the x-y plotter in Fairbanks, Alaska.

which plots the direction of the incident magnetic field on an x-y plotter and which initiates the microprocessor program. Magnetic signals are accepted if they have a zero-to-peak rise time between 2 and 12 microseconds and if they do not reverse polarity within 20 microseconds after the peak. Additionally, any signal is rejected if it has a subsidiary peak larger than the first within 20 microseconds of the first peak.

The x-y plotter is used to record the angle to each flash according to the NS and EW magnetic signal components. A photograph of the processing electronics and an x-y plotter is shown in figure 4. For each flash, a line segment or vector is drawn in the direction of the discharge from a center which represents the station location. When the system is run without the microprocessor, the vector length is proportional to the peak magnetic field of the first stroke in the flash. When under control of the microprocessor, the length of the vector can represent either an average signal strength or a crude estimate of the range based on this average. In order to extend the dynamic range of the x-y plotter, high- and low-gain results are plotted separately, and the inside end of the vector segment is kept a constant fraction of the total length. If a number of discharges are averaged on the same graph, the resulting pattern of vectors points in the direction of the active storm cells. An example of several vector patterns is given in figure 5. During tests in Alaska, the well-defined groups of vectors corresponding to cells were sometimes accompanied by a few smaller, generally backward vectors due to intracloud discharges. In most cases, these backward vectors were easy to identify and ignore; but an electric field sense antenna and improved pulse-shape selection circuits have subsequently eliminated this problem.

The microprocessor digitizes the signals for each return stroke in a flash; calculates the azimuth angle for each stroke; tests the stroke angles for mutual consistency; computes an average angle and the average signal strength for all good strokes; tests whether the computed angle is within a preset interval desired for output; writes the average angle and signal strength vector on the x-y plotter; and outputs the time, azimuth, and the number of strokes to a teletype. In active lightning situations, the microprocessor can store up to 8 flashes in a buffer memory while new data are being acquired and then output all the data as time permits.

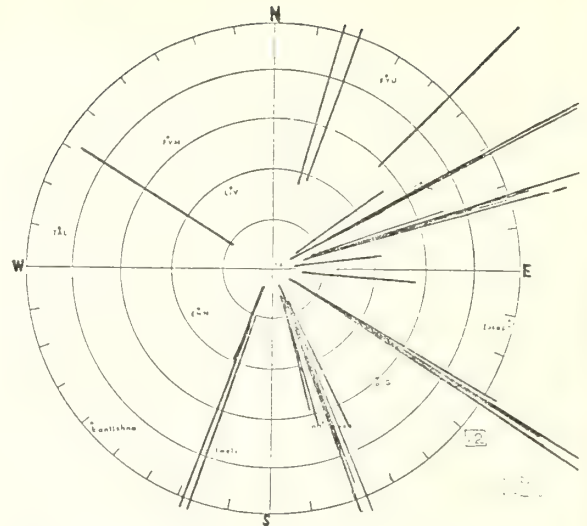


Fig. 5--An example of lightning azimuth vectors obtained at Fairbanks, Alaska, on Aug. 2, 1976. Note the well-defined cells at about 61, 73, 122, 158, and 200 degrees.

SYSTEM PERFORMANCE

The effective range of the above direction-finding system is about 200 nm in interior Alaska and about 300 nm in Florida and Arizona. Large lightning signals can be detected at much greater distances, but beyond the effective range many signals will be missed because they are below the system threshold.

Given the natural variability of lightning, any selection system will necessarily miss some good waveforms, due to fluctuations in shape, and accept some spurious signals. Tests were run on several lightning storms to determine: (a) the efficiency at which return-stroke signals were accepted, (b) the percentage of system triggers which were not good return strokes, and (c) the efficiency at which signals which were large enough to trigger the system, but were not due to return strokes, were rejected. The results of these tests are shown in Table 1. As can be seen in Table 1, the system accepts 70 to 90% of all return stroke signals, and now rejects 97% or more of the improper waveforms. Tucson storms A, B, and C were obtained prior to the addition of an electric field sense antenna and improved pulse-shape circuits. Tucson storms D, E, and F each represent successive circuit improvements.

With the microprocessor, single-stroke

Table 1.--Detector Performance

Storm	(a) Percentage of good return-stroke waveforms which were detected	(b) Percentage of system triggers which were due to improper waveforms	(c) Percentage of improper waveforms which were ignored	Storm Distance (nm)
Fairbanks	68	22	--	125
Tucson (A)	81	10	84	≥150
Tucson (B)	86	8	86	≥100
Tucson (C)	86	5	--	200-300
Tucson (D) ^{1/}	71	3	--	~300
Tucson (E) ^{1,2/}	88	2	97	100-300
Tucson (F) ^{1,2/}	84	1	98	100-300

^{1/} Additional noise rejection circuitry added.

^{2/} Composite average of several storms.

flashes can be eliminated by requiring the lightning flash to have more than one return stroke at the same azimuth. This requirement reduces the overall detection efficiency of ground discharges to about 40% (in Arizona), but restricts the output during very active storms to only those discharges with the highest ignition probability.

The angular resolution of the direction-finding system has been measured to be 1-2 degrees or less on a number of discharges near Tucson, Arizona (Krider et al. 1976). When the lightning strikes over or behind mountainous terrain, the resolution usually decreases to about 2-4 degrees. In Alaska, a number of flashes from the same distant cell would sometimes be plotted at exactly the same azimuth, and this could only occur if the system resolution is a fraction of a degree, in favorable cases.

The large variability in lightning signal amplitudes prohibits the determination of an accurate range based on the signal strength at just one station. Sometimes, however, an approximate distance can be inferred from the average length of a number of vectors in an isolated cell. Of course, if two or more direction-finding systems are operated simultaneously, accurate lightning locations can be determined by triangulation. Also, when multiple

stations are used in coincidence, any spurious vectors due to noise or intracloud discharges will be rejected.

ALASKA TESTS

During the summer of 1976, six lightning direction-finding systems were operated in interior Alaska by the Bureau of Land Management in an effort to improve the detection of lightning-caused fires. Each system operated without the microprocessor and had a useable range of about 200 nm. Six stations, McGrath, Fairbanks, Tanacross, Ft. Yukon, Bettles, and Galena, covered a total area of about 250,000 nm² with a multiple-station overlap in coverage over about 130,000 nm². Reliable communications were not available between the sites, so each station was operated independently. Weather radar contours were available on hourly intervals at most locations. The lightning vectors were used to pinpoint those radar echoes which were actively producing lightning, and also to indicate which echoes were not active. The angular resolution of the detectors was usually more than sufficient to resolve individual cells of electrical activity within large cloud systems.

The locations of all 1976 lightning fire starts in interior Alaska were accurately correlated with the directions of lightning vectors recorded at one or more sites. BLM fire management and fire weather personnel

found the detector a valuable indicator of the presence and direction of lightning. On several occasions, cloud-to-ground lightning was detected from clouds with radar tops of less than 20,000 ft, where the ambient air temperature was only about -20°C . These cases are of particular interest to both the fire weather and the research communities.

All Alaska tests indicate that the direction-finding system is quite suitable for lightning fire detection and that it can be operated by non-technical personnel. In future years, communications will be added to the Alaska network and triangulation techniques will be employed to pinpoint the locations of all discharges which are detected at more than one station.

Acknowledgments.--It is a great pleasure to acknowledge the generous assistance which was provided by a host of BLM and other personnel during the Alaska tests. We are particularly grateful to R. M. Clithero and J. P. Kastelic for their encouragement and helpful suggestions throughout the program. The microprocessor subsystem was developed with the assistance of Mr. David Scheer of Analog Precision, Inc., Tucson. This work was supported in part by BLM Contract YA-512-CT6-81 MOD1.

REFERENCES

- Herrman, B. D., M. A. Uman, R. D. Brantley, and E. P. Krider.
1976. Test of the principle of operation of a wideband magnetic direction finder for lightning return strokes. *J. Appl. Meteor.* 15:402-405.
- Krider, E. P. and R. C. Noggle.
1975. Broadband antenna systems for lightning magnetic fields. *J. Appl. Meteor.* 14:252-256.
- Krider, E. P., R. C. Noggle, and M. A. Uman.
1976. A gated, wideband magnetic direction finder for lightning return strokes. *J. Appl. Meteor.* 15:301-306.
- Krider, E. P., and G. J. Radda.
1975. Radiation field waveforms produced by lightning stepped leader. *J. Geophys. Res.* 80:2653-2657.
- Krider, E. P. and C. D. Weidman.
1976. The fine structure of lightning return stroke waveforms. Submitted to *J. Geophys. Res.*
- Tiller, J. A., M. A. Uman, Y. T. Lin, R. D. Brantley, and E. P. Krider.
1976. Electric field statistics for close lightning return strokes near Gainesville, Florida. *J. Geophys. Res.* 81:4430-4434.
- Uman, M. A.
1969. *Lightning*. New York, McGraw-Hill, 264 pp.

Session III
Fire Danger, Fire Weather and Fire Ecology

Chairman: James H. Richardson, Chief
Division of Fire and Protection Management
United States Department of the Interior
Bureau of Land Management
Washington, D. C.

Meteorological Needs of Fire Danger and Fire Behavior¹

Craig C. Chandler^{2/}

Abstract.--More than half the weather-related incidents causing loss of life or property during large wildfires are the result of mesoscale phenomena. Neither the National Weather Service nor the forest fire services are emphasizing mesoscale phenomena in their research or training activities.

Unfortunately, the overwhelming meteorological need if we are to obtain significant improvement in fire danger rating accuracy and fire behavior prediction reliability is much easier to define than it is to achieve. We need accurate, timely forecasts of mesoscale phenomena. Over the past two decades we have seen marked improvement in the general fire weather forecasts as a result of both improvements in the tools and techniques for synoptic analysis by the weather service, and improved communications, forecast packaging, and mutual understanding of requirements by both the fire services and the weather service. These synoptic forecast improvements have paid off handsomely in better, more cost-effective preparedness planning by all major fire agencies. However, they have been of very little help to the fire boss or fire behavior officer in determining expected changes in fire danger and fire behavior on individual campaign fires.

Similarly, over the past two decades, the fire services have achieved a marked improvement in meteorological understanding by training all fire-going personnel in the rudiments of topometeorology. However, this training too has had a less than expected effect in decreasing the number of unanticipated meteorologically related incidents leading to severely adverse fire behavior in campaign fire situations.

Before going further, I need to define synoptic, meso-, and toposcales, since they

are used in this paper in a slightly different sense than that of either Geiger or Schroeder. By synoptic scale phenomena, I mean those weather changes that can be predicted by analysis of data drawn from observations taken at the basic synoptic network stations. By topographic scale phenomena, I mean those weather changes that can be predicted from analysis of observations taken at a single location together with a knowledge of the surrounding vegetation and topography plus synoptic aids. Mesoscale phenomena, then, are those weather changes which result from causes too localized to be identifiable from the basic network observations, yet too widely separated to be reasonably deduced from observations at a single local station. The timing and strength of marine air penetration into coastal valleys is perhaps a classic example.

Why haven't our improvements in fire weather forecasting and fireman's fire weather training resulted in comparable decreases in large fire incidents? In probing for a reason I examined 32 fire case histories that have been used in national fire behavior training courses since 1957. In only four to six of them were synoptic scale changes a significant feature in altering the fire behavior after the fires had escaped initial attack (I say four to six fires since the Sundance and Okanogan fires were somewhat anomalous). In only one-third to one-half of the fires were the specific incidents selected for study reasonably predictable from single station observations. This figure is fairly loose since most of the examples were derived from single station data by recapitulating backwards from effect to cause. Nevertheless, the results agree well with those of the fire incidents that I have personally investigated--somewhat more than half of the loss of life and loss of acreage in weather related large fire incidents results from mesoscale phenomena. Let's look at two

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specific cases to illustrate this point.

The Rattlesnake Fire was a small brush fire that started on the Mendocino National Forest in California on the afternoon of July 9, 1953. It was controlled that evening after covering less than 1,500 acres, but in the interim 15 men had been burned to death.

The Rattlesnake Fire was situated in the western foothills of the Sacramento Valley in moderately steep topography at an elevation of 2,000 feet. The Valley floor, 5 miles to the east is at 600 feet, the North Coast Range crest, 18 miles to the west varies in elevation from 6,000 to 7,500 feet. West of the crest lies the Eel River drainage running south to north, then a lower range of mountains, then, 65 miles from the fire, the Pacific Ocean.

The fire originated on the south side of a road that was built along the south side of Powderhouse Creek. To the south, the slope rises 600 feet in slightly less than half a mile to Rattlesnake Ridge. To the north the slope rises 350 feet to a saddle 1,000 feet from the creek and then drops off 1,100 feet to the bottom of Grindstone Creek a mile further north. Powderhouse Creek itself has its headwaters at an elevation of 2,100 feet, just a few hundred yards west of the fire. But Grindstone Creek runs 23 miles to the northwest and drains a sizeable chunk of North Coast Range up to 7,500 feet elevation. Immediately opposite the Powderhouse saddle, Grindstone Creek makes a sharp bend to the east where it empties into the Valley.

During the afternoon the fire moved upslope and control efforts were aimed at stopping the fire from slopping over Rattlesnake Ridge into the next drainage to the south. Plans were to construct a line along Rattlesnake Ridge, anchor it to the road at both ends and fire out from the top down. Burning out operations were begun at about 5:30 p.m. At about 8 p.m. the firing crew was turning the northeast (upper) corner where the fireline tied to the road when local turbulence and fire whirls developed which started several spot fires below the road. Firing out operations were stopped and all but one spot fire were extinguished with tankers. A 19-man crew was assigned to the spot fire that was beyond control by tankers. By 9:30 the spot fire was contained and firing out operations resumed--this time from both ends of the road to make up for lost time. At 9:45 an Assistant Ranger and four men carried lunches to the crew on the spot fire. The line around the spot fire was complete and the Assistant Ranger decided to have the crew eat there before returning to work on the main fire. At 10 p.m. the wind shifted abruptly from upslope to westerly (cross-slope). This

caused the main fire which had been slowly backing down towards the road from Rattlesnake Ridge to build up and move rapidly to meet the burning out fire strung along the road. As the two fires met several more spot fires were started below the road, at least one of them across Powderhouse Creek on the south facing slope leading up to Grindstone saddle. This spot, which was out of reach of tankers, quickly burned upslope to the saddle where it was met by a strong northwest wind and took off very rapidly as a wall of flame moving southeast down the Powderhouse drainage. It was now approximately 10:20 p.m.

When the blowup occurred, the 25 men on the spot fire were strung out eating lunches. The nine men highest up the slope elected to go uphill and try to outflank the fire. They barely made it. The 15 men lower down decided to go downhill and downcanyon and try to outrun the fire. The first man was overcome when he had gotten 600 feet from the spot fire, the last man made it 1,500 feet. All 15 died. The fire was controlled before morning at 1,400 acres.

The post-fire investigation showed that the basic cause of this tragedy--the sudden surge of wind through Grindstone saddle and down Powderhouse Creek--is a normal summertime occurrence in that location. It occurs at the end of every hot, clear day in the upper Sacramento Valley when the valley winds give out and the cold air from the mountains slides down Grindstone Creek and, coming to a right angle turn, ride up the slope, through the saddle and down the other side. The timing of this surge is regular as clockwork: between 9:15 and 10:45 p.m. Its duration is short: 30 minutes to an hour. But its occurrence is not one that would normally be predicted, either by a National Weather Service meteorologist with a standard training and background, nor by a Federal or State fire boss with a standard training and background. The cause of the Rattlesnake tragedy lay one drainage away from the fire scene--too far away for the fire boss, and encompassed an area of less than 100 square miles--too small for the synoptician.

A second example is similar yet opposite.

The Elsinore Front on the Cleveland National Forest in southern California is a steep, brush covered, east facing scarp that, in less than a mile, rises from Lake Elsinore at 1,300 feet to El Cariso Pass at 3,200 feet. West of the pass the land slopes more gently to the Pacific some 20 miles away. A two lane paved State highway winds across the face of the front to connect the interior valley towns to San Juan Capistrano on the coast. At 6 p.m. on August 8, 1959, a car failed to negotiate a curve, went

over the embankment, rolled 600 feet down the slope and burned. The fire was reported almost immediately and California Division of Forestry crews responded from the town of Elsinore and U.S. Forest Service crews from El Cariso Guard Station just west of the pass. The fire was spreading rapidly downhill pushed by a steady downslope wind. The CDF crews were assigned the lower edge of the fire with instructions to keep the fire from crossing the highway and to protect ranch properties and outbuildings that dotted the edge of the lake. The Forest Service crew was to control the upper edge of the fire, keep it from crossing the highway and construct a line down the fire's north flank to complete containment.

After two attempts to construct a flank line had to be abandoned, the Forest Service Ranger decided to fire out a half mile of highway and tie in to a 150 acre burn that had occurred 3 weeks before. At about 7:30 p.m., 25 men were spaced out between the fire edge and the old burn and set to chopping brush along the edge of the highway to facilitate the firing out operation. The actual firing was to proceed from the fire edge up the road to the old burn. By 8 p.m. the four-man firing crew supported by three tanker-pump units had progressed about 200 yards up the road. Then, suddenly, the wind stopped and, according to survivors, "for about half a minute the fire seemed to be burning in a vacuum." Then all hell broke loose. Within a few seconds sheets of flame, sand, gravel, and rocks the size of baseballs whipped across the 25 to 35 foot wide highway along a 100 to 200 yard stretch of road at the head of the backfire. At the same time the main fire made a series of runs up the small drainages along the entire stretch of road leading to the old burn.

The tanker operators immediately put their equipment into reverse gear and backed downhill to where their backfire had already burned out a safe distance. All 29 men ran down the road after the tankers. The firing crew and the first six men reached safety unharmed. The 12 men in the middle received various degrees of burns on their hands and faces. The seven men furthest uphill were critically burned and five of them died of their injuries. The paint on the downslope side of the middle tanker had melted and was imbedded with sand and small pieces of gravel. The paint on the uphill tanker had been burned and sandblasted completely away.

What caused this tragedy? Why should apparently well established downslope winds reverse themselves in late evening? What could cause a relatively small fire to sweep flame across a 25 to 35 foot wide highway nearly simultaneously along a one-half mile

front? As in the Rattlesnake disaster, the keys lay some distance from the fire itself.

In 1959 "Lake" Elsinore contained not a drop of water, but was a barren, sun-baked mud flat 2 miles wide and nearly 5 miles long situated 2 miles east of El Cariso Pass and slightly over a mile east of the base of the mountains. In the 100 degree plus days of summer, convection from the dry lakebed is strong enough that it is a favorite haunt of sailplane pilots. To the east El Cariso Pass is the lowest spot where cool air from the Pacific can pour in to the interior valleys. In the morning when the east facing slopes of the Elsinore front warm more rapidly than the lakebed upslope winds are formed. At noon, when upward convection from the lakebed is fully developed, the heated slopes still provide enough buoyancy to keep the eastward flowing cool air from reaching the surface. But by early afternoon when the sun hits obliquely on the 40 percent slopes, downslope winds start forming and reach their peak velocities prior to sundown. When the lakebed is shadowed, an hour or two after the slopes, convection stops apparently rather abruptly. As the air in the basin stabilizes, inflow through the pass is reduced and the downslope winds abate, or even reverse themselves for an hour or two if the slopes are still warm enough. Later in the night radiational cooling produces "normal" downslope winds along the front.

At the time of the breakdown in downslope winds, the Decker Fire was actively burning in flashy fuels on an 80 acre flat at the base of the mountains and bounded on two sides by spur ridges. When the winds stopped, the sudden release of heat set up an eddy over the flat which moved upslope and developed into one or more large and extremely intense fire whirls. As one whirl moved upslope to the scene of the tragedy it triggered runs up all the spur drainages in its path. Fortunately, the whirl itself crossed the road at a point where the burning out operation had already removed appreciable fuel. Otherwise the loss of life in this incident would undoubtedly have been greater.

Here again we have a situation that is a normal daily climatic phenomenon for the area involved, but one which would not be readily predicted by either the synoptician nor the topometeorologist.

So what do we do about it? I don't claim to have all the answers, but one thing I'm sure of--we need to have more top quality people thinking about it. Two decades ago, when Forest Service Research was considerably smaller and poorer than it is now, Countryman and Schroeder initiated a series of "Fireclimate

Surveys" that were intended to provide an initial series of case history studies from which generalizations about the dynamics of mesoscale phenomena could be made. Over the years this effort petered out as their time and resources were redirected towards other, more seemingly urgent lines of research. Two decades ago, when the U.S. Weather Bureau was considerably smaller and poorer than today's National Weather Service, fire weather forecasters used to spend part of their winters analyzing and documenting their past seasons fires with the aim of providing better localized service. I haven't seen any such analyses lately. Again, I suppose, because of "higher priorities" elsewhere. I suggest we reexamine our priorities. There is a large gap in our training, our forecasting aids, our observation networks, and even in our basic understanding of weather processes on the mesoscale that will have to be filled before we can expect to see significant improvements in our fire weather forecasts on large fires.

Two actions could be taken now, without any new grandiose programs, or even any new budget increases. We, both the fire weather forecasters and the fire behavior officers, could and should return to the habit of carefully recapitulating and documenting the meteorological history of every fire we attend.

Time and time again case histories have proven their value as training aids and as sources of research data. To neglect this documentation because of other work pressures after getting back from a fire is to waste at least half of the value of having been on the fire in the first place.

Second, we can and should insist on more and better weather observations on both prescribed burns and large wildfires. I have always felt it anomalous that the Weather Service spends at least five times as much to equip its mobile units with telefax equipment as it does to provide them with portable recording weather stations. It is, of course, easier to draw curves from a single data point, but the results don't necessarily inspire much confidence. In some instances the fire agencies have tried to make up for this deficiency by utilizing their own weather observers (the Weather Security Watch system established by John Dell in Forest Service Region 6 is a good example), but this is a poor substitute for four to six recording stations strategically placed by the fire weather forecaster.

So in conclusion, as in the beginning, what we need are accurate, timely mesoscale forecasts. Whether or not we ever get them is largely up to the people in this room.

Meteorological Needs for Fire Management Planning¹

R. L. Bjornsen^{2/}

There are five principle categories of fire management planning which have meteorological needs; many of them common. Meteorological data is essential to execution of fire plans. The data, historical and forecasted, is an integral part of each fire plan. There is shared responsibility between user agencies and National Weather Service to negotiate a common plan which will translate needs into reality.

Planning is not unique to fire management. Rather, it is a common denominator in the success equation for all endeavor. But fire managers, like others who seek goals and objectives, must develop plans to achieve them. In his case the fire planner has meteorological needs which must be satisfied. Before looking at these let us see the type of plans the fire manager deals with.

Traditionally fire management planning falls into the following categories:

- Presuppression
- Preparedness
- Prevention
- Suppression
- Prescribed Burning
- Natural Fires

Later we will see how each of these categories has meteorological needs. But first let us clarify that this paper will treat meteorological needs for fire management planning in a broad context, rather than the specifics of data required and hardware configuration.

Earlier in this conference Tikkala ^{3/} and Wilson ^{4/} set the stage for protection agency needs in the operational arena. One thing made abundantly clear by their papers is that meteorological data is essential to execution of fire plans. We cannot deny this truism because the effects of weather, short and long term, upon the wildland resources we administer are profound. The fire planner must incorporate meteorological data into his plans if they are to be successful in operational execution.

It is meteorological data, historical and forecasted, which then becomes an integral part of each fire plan. Often a common meteorological data base will serve more than one type of plan. This fact needs to be exploited by the planner. Nearly every plan has a unique requirement for meteorological data. Let us examine what these needs are for the principal categories of plans. Since there is a commonality between various plans, Table I would seem to serve well to identify commonality yet focus on unique needs where they exist.

The tabulation is not all inclusive, but only intended as a guide to place meteorological needs for fire management planning in perspective and emphasize the important role which meteorological data plays in the fire planning process.

^{1/}Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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^{4/}Land Managers Needs for Weather Service and Advice.

METEOROLOGICAL NEEDS FOR FIRE MANAGEMENT PLANNING

TABLE I

<u>PLAN</u>	<u>NATIONAL DATA BANK FIRE WEATHER STATISTICS</u>	<u>EXTENDED FORECASTS 24-72 HOURS</u>	<u>LONG RANGE OUTLOOKS</u>	<u>WILDLAND DROUGHT FORECASTS</u>	<u>PORTABLE RECORDING WEATHER STATIONS</u>
Presuppression	X				X
Preparedness	X	X	X	X	X
Prevention	X		X	X	
Suppression		X	X		X
Prescribed Burning		X	X	X	X
Natural Fires	X			X	X

With one exception I will not burden the reader with descriptions of the various categories of plans, he will have to accept they serve mostly different goals and objectives. The exception is natural fire plans; goals, objectives, and execution of which can vary greatly between agencies.

Suffice it to say for purposes of this paper, that natural fire plans are those which accommodate fires that are usually monitored (for whatever objective), as they burn rather than fires where aggressive suppression action is taken.

How do we translate needs into reality? This is a shared responsibility between user agencies on the one hand and National Weather Service (NWS) on the other. Note I have named NWS specifically here. This is because user agencies universally identify NWS as the principal entity for supplying meteorological input to meet both planning and operational needs, particularly in the fire area.

Back to reality. The user agencies have responsibility for identifying their needs, establishing performance expectations and determining program target dates. Whereas NWS has responsibility for determining how meteorological needs will be met, when they can be met and funds required to support the programs, then becomes a joint responsibility to negotiate a common plan which will translate needs into reality.

Returning to the occasionally abstract world of the fire management planner, we see that meteorological data is essential to execution of fire plans and therefore essential to the planning process. Somewhere, somehow we must translate these needs from the drawing board into reality. There is no panacea for achieving this, we can only be encouraged by the anonymous simile which says: everything that is done in the world is done by hope.

Meteorological Resources for Land Management¹

Robert C. Lamb²/

Abstract, --Several types of meteorological resources are available to land managers. Among those are data, service, research, and the land managers themselves. We are not utilizing existing meteorological data as effectively as is needed and we need better sampling over time (both throughout the year and diurnally in the Forest and rangeland environment).

The special service meteorological resource for land management does not exist. It should and we should take the steps now.

The research resource must insure that its products past and present are carried through to operational usefulness.

The users of meteorological resources are a resource in themselves, and to be effective, must identify and fulfil the responsibilities necessary to effective use of this resource.

The comments here are designed to assist in defining the meteorological resources available and potentially available to land managers. Positive progress requires commitment by users as well as providers of meteorological resources.

I INTRODUCTION

Dr. Furman has just provided an example of a specific meteorological resource for land managers. I want to take this opportunity to broaden our scope in examining meteorological resources. To address this area, I have stratified meteorological resources into four categories:

1. Meteorological Data Resources
2. Meteorological Service Resources
3. Meteorological Research Resources
4. Meteorological User Resources

I established these categories because I believe it is important that we look briefly at the strengths and weaknesses of each. Hopefully, the comments to follow will help take us a step toward better understanding and utilization of meteorological resources for land management.

II METEOROLOGICAL DATA RESOURCES

In the States of Oregon and Washington, substantial meteorological data are collected. These states are used because of my familiarity with them, but they are typical of much of the rest of the country. Weather data is available from:

1. About 300 fire weather stations taken on a daily basis during the fire season. This data spans from a few years to several years and is available in the National Fire Weather Data Library at Ft. Collins, CO. Brink, & Furman.
2. 350-400 climatic stations that measure maximum and minimum temperature and precipitation daily.
3. Three upper air monitoring stations (Quillayute, Wash., UIL, Salem, OR, SLE, & Medford, OR, MFR.)
4. An interagency Columbia River basin hydro-met network encompassing numerous stream gaging, and precipitation and snow measurements.
5. One weather surveillance radar system with additional back up from ARTC radars.
6. About 35 hourly reporting stations taking complete observations excluding solar radiation and soil temperature in both States.
7. Satellite pictures from the GOES on a half hourly basis with selectable resolution from 1/2 mile visual during the day to 1, 2, or 4 mile resolution IR and visual. Incidentally, these are not available to special service

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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program offices.

Data mentioned in two through seven above is stored at the National Weather Records Center in Asheville, NC. This list is not all inclusive, but nevertheless represents the collection and storage of enormous quantities of meteorological data. In spite of this substantial resource, we have very limited data and observations from the actual land management environment exclusive of the daily observations from fire weather stations during the fire season.

Some items are worth emphasizing at this point. First, we are not effectively utilizing the meteorological data that presently exists to assist in land management activities. e.g., climatological summaries, including the use of conditional climatologies designed to specifically address land management needs. Secondly, there still exists a need for better sampling of the Forest and rangeland environment both diurnally and throughout the year. Finally and of substantial importance is the need for quality equipment and observations at land manager maintained sites.

III METEOROLOGICAL SERVICE RESOURCES

Let us now examine briefly the meteorological service resources available in the States of Oregon and Washington, there are:

1. Fourteen manned weather service offices in the two States, eight of which are staffed with professional meteorologists and six with meteorological technicians. Six of these offices have specialized Fire Weather programs.
2. Two weather service forecast offices providing forecast guidance to the respective States.
3. One river forecast center manned by professional meteorologists and hydrologists.
4. One weather service office for Agriculture manned by a professional meteorologist.

Again the service resources here are not all encompassing, but do indicate substantial service resources that receive, develop and disseminate information that may be useful in land management activities.

Let us reflect momentarily on the service resources, specifically the

specialized service programs, e.g., Fire Weather and Agricultural weather. The special service programs and people in these programs are important because they, by design address specific needs. They differ in important ways from people in other meteorological service programs in that they:

1. Have an opportunity to conduct training for the users in basic weather and forecast interpretation. This is an extremely important function because it relates to the area of greatest potential improvement in forecast information that exists at this time, i. e., communications. For example, have you ever asked yourself how much of the information contained in the narrative portion of the forecast goes unused because it is not understood? Have you thought about some means of delivering live weather briefings to land managers?
2. Have an opportunity to develop a better understanding of user activities and needs and thereby select, develop and provide weather and forecast information that is most appropriate to the users needs.
3. Can conduct localized forecast improvement, climatological studies etc., that will enhance the forecast service and use of other meteorological information.

You should remember that there are special meteorological service programs in the Fire Weather, Agriculture, Marine, Aviation, etc., but, there is no specialized service program addressed to the sum total of Forest and rangeland management. Can we derive positive benefits through considering the pooling of Agriculture and Fire Weather and expanding these into a viable land management special service program?

IV METEOROLOGICAL RESEARCH RESOURCES

The data and service resources mentioned above related to the States of Oregon and Washington but are generally typical of other areas. The meteorological research resources are more limited and we will look briefly at these on a National level. They are:

1. Research at the National level in Washington by the National Weather Service principally oriented toward model improvement, development and use of model output statistics.
2. Meteorological research conducted by the Forest Service at the three fire laboratories (Macon, Georgia; Riverside, CA; and Missoula, MT,

the Mountain Meteorology project at Ft. Collins, CO. and peripheral work at several hydrologic laboratories.

3. Meteorological research conducted at several universities.

4. Meteorological research conducted, completed, in journals or papers residing on shelves, but otherwise unused.

Again this is not all encompassing. However, it is well recognized that meteorological research specifically oriented to land management activities is very limited indeed. Even the Forest Service meteorological research has been principally oriented towards fire. The Forest Service appears ready, as evidenced by the current scope of atmospheric science research, to address the broader concept of meteorology and land management.

Item 4, completed research is the resource that is most readily available, but application in present forms may prove difficult without further refinement and framing into an operational mode. By the same token, we need to have ongoing research carried on through to the point that it is also operational. This is of particular significance when you consider that the land managers of whom we speak are not either academically or operationally trained in the use of meteorological resources.

V USERS OF METEOROLOGICAL RESOURCES

It may seem strange to you that I would mention users when I talk of meteorological resources. However, I have become increasingly convinced that this is a resource that ties the total picture of meteorological resources together. The user must understand that he has a responsibility to know how to effectively use resources available to him as well as have the ability to maintain and collect additional resources (Weather stations and observations).

Earlier, it was stated that training is an essential part of an effective specialized service program. It is equally important that users of meteorological resources be ready, willing and able to receive that training.

The philosophy to be imparted here is that the people who provide meteorological resources are not the only people who have responsibilities related to the use of meteorological resources. For example, how many position descriptions in your agencies or companies make it clear that the individual has a responsibility to know how to effectively utilize weather information? The simple knowledge that a responsibility

exists, allows for accountability and provides a substantially better stimulus to receive training and make effective use of training.

Who is responsible for maintaining quality standard weather stations and observations? Will an annual or less frequent visit to a weather station suffice? The States of California, Oregon, and Washington and Region Six of the USFS have meteorologists on their staff to assist in the application of meteorological resources. How many other companies, states, Regions and other land management agencies have taken that same step?

VI SUMMARY

In summary, we indeed have substantial meteorological resources. These cover enormous quantities of data, substantial services, research and users or potential users. Relative to application of meteorological resources to land management, we fall far short in several important areas:

1. We are not effectively utilizing existing climatological data.
2. We are in need of better sampling of the land management environment.
3. We are not receiving adequate training and local forecast improvement work from existing special service programs.
4. We do not have a special weather service program that addresses land management needs as such. Present services are bootlegged on other programs.
5. Much of the meteorological research in the past has not been carried far enough to become operationally useful to land managers.
6. Users or potential users of meteorological information have not accepted or identified their own responsibilities for effective use of meteorological resources.
7. We need to develop new and better ways of communicating current and forecast weather information to land management people.

We can move forward in the effective use of meteorological resources for land management. Progress in that direction requires action on the part of research, operational meteorologists, and the land managers. Furthermore, to be effective, the action should be a combined and sustained effort. I say this because of concerns I have seen expressed regarding the Fire Weather Service. I believe these concerns are a positive indicator of desired improvement in that part of a special service program. I do not see evidence of what I think should be equal concerns in the other areas, e. g., land managers, research, and data resources. Furthermore,

I have not seen concerns for doing the total job relative to land management which is indeed much broader than Fire weather.

Are we ready to address a special weather service program with support from land managers and research whose mission is meteorological and climatological support to land management? Does this concept better fit the needs of land managers and will we achieve more effective benefits from the dollars and effort expended?

I believe the answers to the above questions are affirmative and that we can move a long way forward in the application of meteorological resources for land management. This

move ahead requires a definite commitment on the part of users as well as providers of service and research.

LITERATURE CITED

1975, Brink, Glen E. and Furman, William R. The National Fire Weather Data Library: What it is and How to use it.

USDA Forest Service
General Technical Report RM-19
Rocky Mountain Forest and Range
Experiment Station, Ft. Collins, CO.
December, 1975

Meteorological Resources for Land Management¹

R. William Furman^{2/}

Abstract.-- A collection of weather observations that may be described as a computerized meteorological data source has been made available to users on the USDA computer in Fort Collins, Colorado. This data library is a source of unique data since most of the observations are from remote forest and mountain locations. Many of the stations have records exceeding 20 years. The data in the library is accessible either in remote batch or interactive mode. An integral part of the library is the support programs which make the library highly user oriented and allow the user to extract selected amounts of data for his use. The purpose of the library is to make meteorological data easily available to land managers and to promote the use of meteorological data in resource planning.

In this era of environmental awareness, managers of public lands must be aware of possible outcomes of any management practices they prescribe. They particularly need site weather data from the managed areas--both real-time information and historical data--for input to fire-planning and water-yield models to name two good examples. Improvement of fire weather forecasts requires historic data for verification efforts. The best long-range forecast a land manager can get comes from an analysis of his climatological data.

Where the analysis of weather data is a part of routine land management practices, the data should be recent, easily obtainable, and in computer-compatible format. Optimally it is desirable to include this year's data into plans for next year. Where forecast verification is concerned, it is desirable to analyze this year's forecasts to make adjustments next year.

The Forest and Mountain Meteorology Project at the Rocky Mountain Forest and Range Experiment Station in Ft. Collins, Colorado, and the National Fire Danger Rating Project in Missoula, Montana have assembled and currently support a Computer Oriented Meteorological Data Library

on a government computer. The COMED Library consists of a collection of recent and historical fire-weather observations, recent fire-weather forecasts, and the support programs necessary to use the Library.

At present the COMED Library consists of more than 1.5 million fire-weather observations from nearly every State and from nearly all fire management agencies including USFS, BIA, BLM, and many States. These data were initially collected by fire managers for input to daily fire management decisions. This effort was necessary because the National Weather Service observing stations were not located where they could monitor weather conditions meaningful to fire danger problems in forested areas. Federal agencies concerned with fire protection established their own network of weather observations stations in locations where the fire danger could be more accurately monitored. This fire danger network has grown to more than 800 stations monitoring weather once daily, usually during the early afternoon when fire danger is the highest.

The main source of most of the recent data in the Library is the fire danger rating interactive computer program AFFIRMS. AFFIRMS archives all fire-weather observations it receives, and at certain intervals commits the archived data to magnetic tape, a copy of which is sent to the Forest and Mountain Meteorology Project in Ft. Collins. These data are made available to the users of the Library within a week of their receipt.

^{1/} Paper presented at the Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, Nov. 16-18, 1976.

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Another source of data is the historic records occasionally received from stations not using AFFIRMS and from old stations. These data are edited for proper format then put on the Library.

The COMED Library was designed to facilitate the archiving and retrieval of the large number of fire-weather observations used in our research effort. Because of a similar need for the same data by fire planners, a copy of the Library was moved to the USDA Fort Collins Computer Center and made available to all users.

The Library system has four main parts:

- 1) Collective tape
- 2) Library tapes
- 3) Forecast tapes
- 4) Support programs

As data are received from AFFIRMS or any other source, they are edited, sorted, and merged onto the collection tape. These data are available to anyone having a need for current-year data. In January of each year the collection tape is merged onto the Library tapes and a new collection tape is started.

The Library tapes are the repository for all but data received during the current year. The Library tapes are a sequence of tapes on which the fire-weather observations are stored by station number, then by date.

Forecasts received from AFFIRMS are stored on a separate Forecast tape. These forecasts are made available in the same manner as data on the collection tape for the current year; then they are destroyed. No historic forecast data are kept. Retrieval of information stored on the Collection, Library and Forecast tapes is facilitated by a collection of routines called GETDATA available to all users as part of the Library system. These routines make the Library a user-oriented system. The tasks GETDATA will perform are:

- 1) Obtain file names of all data files, along with data limits on the contents of the file.
- 2) Obtain a station-year-record inventory of a selected data file.

3) Create a user file of selected station-years of data from any or all of the Library and Collection and Forecast tapes.

4) List data from user data file.

As a modest degree of protection against loss of data, two duplicates of the entire Library, Collection, and Forecast tapes are kept: one at CSU and one at the Rocky Mountain Station.

In summary, we have described a computerized meteorological data source designed to be used by people who are not computer specialists. This includes land and resource managers.

The Library is a source of unique data since most of the observations are from remote forest and mountain locations. Many of the stations have records exceeding 20 years. The data in the Library are easily accessible in either remote batch mode or interactive on the USDA computer in Fort Collins, which is available to most land management agencies. ^{3/}

Relatively recent fire-weather observations and forecasts from AFFIRMS are available as well as historic observations. Even though most of these station records are seasonal, they may be used with year-round records from the National Weather Service climatological stations to estimate conditions at the fire-weather stations year round.

One of the important uses of this data library is to establish climatologies of the fire-weather stations. Many have records of sufficient length to obtain stable estimates of the climate variables. Efforts are underway to help fire and land managers determine what a useful climatology should contain, and help them use it.

^{3/}Furman, R. William and Glen E. Brink, 1975. The National Fire Weather Data Library: What it is and how to use it. USDA For. Serv. Gen. Tech. Rep. RM-19. 8p. Rocky Mtn. For. and Range Exp. Stn., Fort Collins, CO 80521

The National Fire-Danger Rating System — Latest Developments¹

John E. Deeming^{2/}

Abstract.--Extensive use of the 1972 version of the National Fire-Danger rating System has pointed up deficiencies that the 1978 update is expected to correct. Eighteen fuel models will be provided as well as a completely overhauled fire occurrence module. The system will respond to longer-term drying, and changes have been made that will make the system better reflect seasonal trends in fire danger due to changing sun angle and day length.

INTRODUCTION

Fire-danger rating, like all technologies, is advancing. The current development program, which began in 1968, produced a system based on equations that describe the physical processes of moisture exchange between fuels and the environment. It also considers the effects of wind, slope, fuel moisture, and fuel particle and bed properties on the combustion processes. The system provided indexes relating to rate of spread, available fuel energy, fire containability, and fire incidence (Deeming and others 1972).

The system, as it was released for use in March 1972, represented the state-of-the-art of fire research in the United States. At present, the National Fire-Danger Rating System (NFDRS) is being used by all Federal land management agencies and by fire management organizations

in 39 States. Last summer in the Continental U.S. and Alaska, more than 750 fire-weather observations per day were being processed by the AFFIRMS time-share computer program (Helfman and others 1975). An additional 500 observations per day are estimated to have been processed manually or by locally operated computers, as is done in Hawaii.

When the NFDRS was released in 1972, an update was planned for 1978 to correct the deficiencies that were expected to surface with widespread use. The NFDRS Research Work Unit, located at the Northern Forest Fire Laboratory, has nearly completed this task. In this paper, the major problems in the 1972 NFDRS are identified and the planned corrective measures are described.

RESPONSE TO DROUGHT

Because the largest fuel considered in the 1972 NFDRS had only a 100-hour timelag, the indexes fail to reflect the effects of long periods of below-normal precipitation. Previous research had shown that fire behavior is almost totally governed by the condition of fuels less than about 3 inches in diameter, so the initial problem was to discover the avenue by which long-term drying influences fire behavior.

The most logical and intuitively acceptable response to long-term drying was hypothesized

^{1/} Paper presented at the Society of American Foresters-American Meteorological Society Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, November 16-18, 1976.

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to be the moisture content of the live fuels--herbs, forbs, and the twigs and foliage of woody shrub species. In addition, by using Rothermel's spread model (Rothermel 1972), we determined that dead fuels up to 15 cm (6 in) in diameter with a surface area-to-volume ratio of $3.5 \text{ cm}^2/\text{cm}^3$ ($9 \text{ in}^2/\text{in}^3$) should be included. Thus, we felt that the 1,000-hour timelag class could be justified for some of the fuel models.

Predictive equations for the 1,000-hour timelag fuel moisture were derived from existing theory (Fosberg 1970), but for the live fuels equation development was much more difficult. The details of the primitive live fuel moisture model that we developed will be published soon.

Briefly, the model considers three classes of live fuels: the lesser vegetation that will cure; the lesser vegetation that will not cure; and the twigs and foliage of shrubs. The moisture contents are assigned standard values when the spring flush is observed. The daily changes in the living fuel moistures are functions of the change in the 1,000-hour timelag fuel moisture value (the sign and magnitude are considered).

Consideration is also given to the climate at the recording station. Five different sets of responses are provided so that the adaptations of native vegetation to the local climate can be accounted for.

A side benefit from the incorporation of this model in the NFDRS is the elimination of the need for direct sampling of herbaceous vegetation by the users. An examination of data from the transects has shown gross inconsistencies which, because of the sensitivity of the system to this parameter, must have produced significant errors in the NFDRS ratings.

I must emphasize the adjective "primitive" in describing the live fuel moisture model. I want to leave no illusions concerning the finality of the solution. Much work remains before an adequate accounting for the phenology of live fuel species can be made.

SEASONAL VARIATION

The 1972 NFDRS tends to overrate fire danger during the late summer and fall. The Canadians have, for some time, accounted for the seasonal variation of insolation and the resulting effects on the moisture exchange processes, but up to this time we have not.

We attacked the problem from three directions: First, the effect of a varying sun angle on the temperature and relative humidity in the

boundary layer are accounted for. These are significant in the calculation of the 1-hour timelag fuel moisture. Second, in the calculation of the moisture contents of the 100-hour and 1,000-hour timelag fuels, instead of a simple average of the 24-hour maximum and minimum equilibrium moisture contents, a weighted average is used to characterize the drying characteristic of the day. As the period of daylight shortens, the nighttime conditions are given increasing weight, thus promoting moisture recovery in the heavy fuels. Third, the fuel moisture analog (half-inch sticks) value is being considered in the calculation of the 1-hour timelag fuel moisture content. Using an analog is by far the simplest approach because all of the seasonal associated influences are automatically accounted for and integrated in the fuel stick response.

Robert Burgan will discuss this aspect of fire-danger rating in a paper later in this conference.

RATING SENSITIVITY

Because of the desirability of utilizing a finite 0-100 scale for the ratings, we made an error in the 1972 NFDRS that has caused many of our users a great deal of concern. We chose such severe conditions to be represented by index values of 100 that fire managers in the relatively moderate fire climates of the country seldom see ratings greater than 8 or 10.

This lack of sensitivity of the ratings to changing burning conditions has caused many to judge the NFDRS inadequate. This is an unfortunate situation because the problem was caused by a poor choice of scaling factors; not by shortcomings in the basic, underlying theory and equations.

The problem has been solved by making the scales open-ended. The spread component is numerically equal to the predicted ideal rate of spread in meters per minute, and the energy release component is numerically equal to available energy in megajoules per square meter. The burning index equals 50 when the predicted ideal flame length is 3.4 meters (11.3 feet). This value was chosen as the basis for normalizing the burning index because there is a significant probability that a fire with this potential will be uncontrollable if it escapes initial attack. This flame length occurs when the fireline intensity reaches 960 watts per meter of fireline (1,000 Btu per second per foot).

These changes will result in a three-to-five fold increase in sensitivity of the burning

index and a doubling of the sensitivity of the spread component.

FIRE OCCURRENCE

In the 1972 NFDRS, the occurrence module was very simplistic. It was based on what turned out to be pretty sound rationale, but we have made some significant changes.

The most apparent change will be the separate ignition, risk, and occurrence indexes for man-caused and lightning-caused fires. This partitioning is justified because the processes are different, and it is only reasonable that man-caused and lightning-caused fires be accounted for separately.

The man-caused fire ignition component differs slightly with the different fuel models. Rate of spread is now a factor along with fine fuel moisture and temperature. The model is a linear model developed from fire danger and fire occurrence data collected in the Northeast. The model remained linear when checked against data from the Southwest. A computer program that analyzes local fire weather and fire report data is being prepared. It will establish the relationship between the index values and probable fire occurrence levels on the individual protection unit.

The lightning occurrence index was developed from data accumulated from Project Skyfire studies in the Northern Rockies. Data on storm size, lightning frequencies, and the prevalence of cloud-to-ground strokes capable of starting fires have been correlated with the five existing lightning activity levels. A sixth lightning activity level has been added to account for the classical "dry" lightning storm situation.

FUEL MODELS

In the 1972 NFDRS, the user is given a choice of nine fuel models. Many users feel that fuels in their areas are not adequately represented, while others have expressed the opinion that such a range of choices is not needed to rate fire danger.

The question of how many fuel models are needed remains unresolved. In the absence of a means to objectively determine an optimum number, we have decided to offer an expanded set of 18 models, leaving the option of utilizing more or fewer models to the user agencies.

Here is a list of the 18 fuel models that we plan to offer. The models carried over from

the 1972 NFDRS are indicated by their alphabetic designator.

Grass and grass-like

Western annual grasses
Western perennial grasses - - - - A
Everglades sawgrass
Tundra

Savannah

Open timber with grass - - - - C

Brush

Mature California chaparral - - - B
Intermediate chaparral
High poccossin
Southern rough (palmetto-gallberry) - - - - - D

Timber

Short-needled conifer--heavy
dead - - - - - G
Short-needled conifer--normal
dead - - - - - H
Long-needled conifer--normal dead
Alaskan upland black spruce
Hardwoods--summer
Hardwoods--winter - - - - - E

Slash

Heavy - - - - - I
Medium
Light

The models have been improved with the addition of 1,000-hour timelag and live fuels where justifiable. Also, the extinction moisture content and percent of the herbaceous fuels that will cure are characteristic of the fuel model.

I must be candid about these fuel models. Very little data exist on the properties of the fuels found in many of the situations that these models are supposed to represent. The exceptions are the grass, chaparral, slash, and southern rough models. Where data were not available, the models were constructed using whatever knowledge was available. They were then adjusted so that the predictions of flame length and rate of spread made using the fire behavior models fell within acceptable limits.

The lack of reliable observations of fire behavior has been a handicap in evaluating the performance of the fuel models. Subjective evaluations by fire management personnel are being made, but more often than not, the opinions conflict.

Perhaps there is a truth emerging that we should face up to. Fuels vary a great deal from one point to another within a type. Stylized fuel models can be very useful, but we should not allow ourselves to develop unreasonable expectations concerning the accuracy of predictions based on these models. A larger number of fuel models will not result in more precise predictions of fire danger. Instead, the uniqueness of the fuel models will be lost and their usefulness will be lessened. Thus for our purposes, a limited number of fuel models is desirable.

THE FIRE SPREAD MODEL

Rothermel's fire spread model remains the basis for the spread and energy release components and the burning index in the NFDRS. Fire behavior modeling is continually evolving and we are taking advantage, when possible, of each applicable advance. At this time, the principal changes to be incorporated into the 1978 NFDRS are: (1) a new calculation of burnout time; (2) an improved calculation of the extinction moisture content of live fuels; and (3) a more realistic handling of live fuels. The model allows for the loss of the energy necessary to dessicate the fuel, and for a positive contribution of energy when and if the live material starts to burn (Albini 1976).

CURRENT PLANS

Three research work units at the Northern Forest Fire Laboratory in Missoula, one in East Lansing, Michigan, and one in Fort Collins, Colorado, have contributed research specifically directed at improving the NFDRS. We feel that

significant progress has been made, and the improvements will be passed on to users in early 1978. For the next 12 months, a major effort will be made in training, in the publication of documenting and informational materials, and in the modification and development of supporting computer programs. Every effort will be made to minimize the impact of the changes on fire management organizations.

LITERATURE CITED

- Albini, F. A.
1976. Computer based models of wildland fire behavior: a users' manual. USDA For. Serv. limited distribution publication available from the author, Northern Forest Fire Laboratory, Drawer G, Missoula, Mont. 59801, 68 p.
- Deeming, J. E., J. W. Lancaster, M. A. Fosberg, R.W. Furman, and M. J. Shroeder.
1972. The National Fire Danger Rating System. USDA For. Serv. Res. Pap. RM-84, 165 p. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.
- Fosberg, M. A.
1970. Drying rates of heartwood below fiber saturation. For. Sci. 16:57-63.
- Helfman, R. S., J. E. Deeming, R. J. Straub, and R. W. Furman.
1975. User's guide to AFFIRMS: time-share computerized processing for fire danger rating. USDA For. Serv. Gen. Tech. Rep. RM-15, 107 p. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.
- Rothermel, R. C.
1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

An Application of Geosynchronous Meteorological Satellite Data in Fire Danger Assessment¹

Marshall P. Waters, III²/

Abstract.--Synchronous meteorological satellite Visual and Infrared Spin-Scan Radiometer (VISSR) digital data are analyzed for surface temperature and cloud cover. These data are blended with conventional meteorological observations made at the surface. An automated technique is described that estimates the one-hour timelag fuel moisture (1-HR TLFM) component of the National Fire Danger Rating System (NFDRS). Comparisons with computed values taken at Fire Danger Stations in the study area are analyzed. The 1-HR TLFM can be estimated for selected meteorological conditions. Automated estimates of the 1-HR TLFM can be made hourly. Distribution of cloud cover can be monitored and mapped each half-hour from satellite visible (VIS) data to indicate surface insolation patterns.

INTRODUCTION

The knowledge of present, as well as antecedent, meteorological conditions is necessary in determining fire danger levels and predicting fire behavior. For the past several years, there have been efforts to provide more timely data for those variables that influence the level of fire danger. The Automated Forest Fire Information Retrieval and Management System (AFFIRMS) (Helfman, 1974) is an example of this. With this system, both the National Weather Service (NWS) and fire protection agencies input weather and forecast data into a time-sharing computer, thus providing more timely data to interested users. A more ambitious system to provide timely data, FIREScope, will telemeter meteorological and fire danger parameters from a network of instrumented platforms in Southern California wildlands to a Synchronous Meteorological Satellite (SMS), then to a time-sharing computer data base.

Another source of timely meteorological data is that collected by the National Environmental Satellite Service (NESS) located at Suitland, Maryland. The VIS and thermal infrared (IR) digital data collected each half-hour from two geosynchronous meteorological satellites

may be a valuable source of meteorological data not currently used in fire danger assessment. This paper describes an automated technique that uses both satellite and ground-based meteorological data to estimate the 1-HR TLFM component of the NFDRS. A forested area in the southeastern United States is used for the study area.

NATIONAL FIRE DANGER RATING SYSTEM (NFDRS)

The NFDRS was developed at Ft. Collins, Colorado, with initial research beginning in 1968. The system is described by Deeming, et al. (1972).

The NFDRS is a structured system using meteorological data (temperature, cloud amount, relative humidity, precipitation, windspeed), objective estimates (dead-fuel moisture), and subjective estimates (lightning risk, man-caused risk, slope, live-fuel moisture, fuel model) to predict forest fire behavior. This allows fire danger indexes of occurrence, fire load, and burning to be estimated, which, when summed, give a seasonal severity measure for the area of concern.

An accurate estimation of the fire danger level of a protected area depends on a valid fuel moisture and weather relationship. A meaningful estimate is difficult due to the

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, Nov. 16-18, 1976.

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complex nature of the forest fuel distribution patterns and the changing meteorological conditions.

The fuel moisture content is one of the major elements in evaluating the fire danger level, as well as predicting fire behavior. In the NFDRS, dead fuels have been classified by their moisture timelags as 1-, 10-, and 100-hour classes. These classes correspond to cylindrical fuels less than one-quarter inch, one and one-quarter to one inch, and one to three inches in diameter, respectively (Fosberg and Deeming, 1971).

One-hour timelag fuels consist of dead hubaceous plants and roundwood less than one-quarter inch in diameter. These fuels are so defined as they are found to lose 63 percent of the difference between starting and final moisture content after drying one hour with conditions of 80°F air temperature and 20 percent relative humidity. The uppermost layer of needles or leaves on the forest floor is also included in this class. The 1-HR TLFM is the moisture content of the one-hour timelag fuels expressed as a percent of the total weight. These fuels, to a large degree, determine whether a fire will start and spread given an ignition source. An estimate of 1-HR TLFM is in itself an assessment of the fire danger.

At fire danger observation stations, the 1-HR TLFM is computed from tables using air temperature, relative humidity, and cloud cover. In this study, the 1-HR TLFM is estimated using cloud-cover information from SMS, thermal IR from SMS blended with air temperatures made at NWS observation stations, and humidity measures made at NWS observation stations.

DATA SOURCES

During the period of this study, the SMS-1 (since replaced by GOES-1) was located in a near-circular orbit above the Earth at an altitude of about 36,000 km. Its geostationary position was such that it remained near zero degrees latitude and 75 degrees West longitude. A more-complete description of the GOES system is found in NOAA Technical Memorandum NESS 64 (Bristor, 1975).

The SMS spacecraft consists of a Visible and Infrared Spin-Scan Radiometer known as VISSR. The VISSR provides for high-resolution visible (1 km) and lower-resolution infrared (9 km) data. The NESS receives the VISSR digital data each half hour from SMS-1 (as well SMS-2 at 0°N and 135°W). The digital data are

imaged and transmitted in picture format to various user communities throughout the United States.

For this study, the VISSR digitized data were collected on magnetic tape from SMS-1 for each half-hour during maximum heating from 1000 to 1600 LST over the study area (Figure 1). Five days in which the coastal area of southeastern Georgia was forecasted to be mostly clear were selected for study: January 2, 5, 14, 15, and 16, 1975. Mostly clear days were required to earth locate the the satellite data.

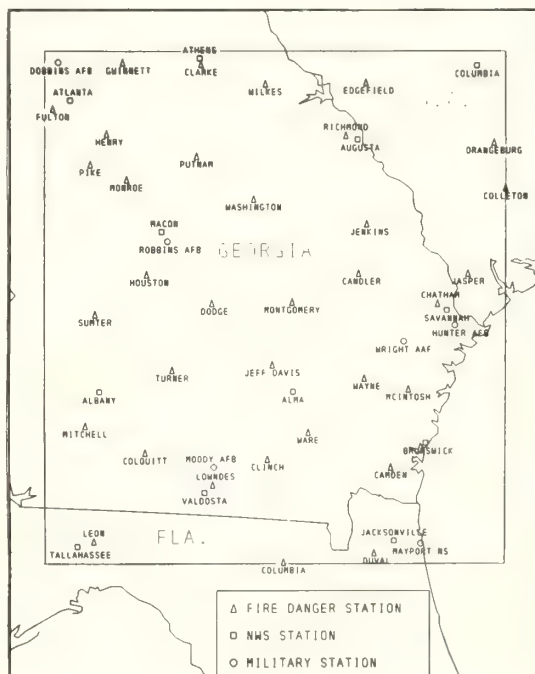


Figure 1. Location of the study area.

The hourly surface meteorological observations were collected from NWS, military, and flight service stations located within the study area. Meteorological data from these stations are transmitted hourly to the National Meteorological Center (NMC) also located at Suitland, Maryland. These coded weather observations become part of the data base used by NMC and retransmitted in different formats to other users. The data are available for recall from the NWS IBM 360/40 computer about 12 minutes after the hour. The hourly observations of those stations located in the study area were recalled from the computer and decoded for each hour from 1000 to 1600 LST for the days selected. Eighteen stations were used for this data source.

The ten-day Fire Danger and Fire Weather Records were used to obtain the fire danger and fire weather information of those stations located in the study area. These data were used to evaluate the estimation technique. Thirty-four stations were used for comparative purposes.

PROCEDURE AND METHODS

Digital visual data from SMS are a measure of the reflected radiation from the Earth scene. It is represented as a count value from zero (darkest) to 63 (brightest) and corresponds to zero and 100 percent earth albedo, respectively. Quantitative estimation of cloud amount over the study area is achieved by partitioning the frequency histogram of count values similar to that done by Miller (1971), but with a different number of partitions and weight values.

The study area was divided into 110 grid blocks. Each grid block was approximately 40-km square and contained 1600 count values representative of the earth albedo about 1-km square each. For clear conditions, the count values represent the albedo due to surface scene only. When clouds are present, the count values are that of albedo due to clouds. If cloud elements are smaller than the resolution of the sensor, then the count value represents an integrated value of the surface scene and the cloud. This also occurs when sampling is done at a cloud edge. When the surface scene and cloud count values are known, cloud amount can be estimated. The mean count value for each grid block was determined at different times of day under no-cloud condition.

Two threshold count values were selected for the area by time of day. The first threshold count value was selected on the basis of the mean value of the scene for the no-cloud condition. Any value at or below this mean count value (darker) was considered a cloud-free sample. The second threshold was selected such that a value at or higher than this value (brighter) was considered a cloud-covered sample. Count values between these two thresholds were considered to be 50 percent cloud-covered samples. Thus by weighting the count values, the percentage of cloud cover can be estimated. It is necessary to continually change the thresholds throughout the day because of the changing sun angle. This estimate of cloud amount for each of the 110 grid blocks was used as one of the elements necessary to estimate the 1-HR TLFM for that grid block.

In addition to cloud amount and humidity, 1-HR TLFM computation requires a measure of air temperature. To estimate air temperature

over the study area, the following assumptions were made: (1) shelter temperature, as measured by NWS stations, varies linearly between stations; (2) the gradient values of the SMS-equivalent blackbody temperatures of the surface-emitted radiance values within the area are representative of the gradient field of air temperature; and (3) absorption of the infrared radiance by the atmosphere is the same over the area.

The infrared sensor of the SMS samples only a narrow wavelength radiation band from the surface within a limited field of view (4x8 km). For the wavelength band being measured, the sensor measures a quantity that is a function of the radiating surface emissivity and temperature of the radiating body.

For every SMS observation, each of the 110 grid blocks contains 50 infrared samples of emitted Earth radiances. As with the visible sensor, the infrared sensor either samples clear surface or cloud or a cloud/ground disposition dependent on cloud amount and pattern within each grid block. For clear targets, determination of surface temperature is relatively easy; however, partly cloud conditions are more difficult.

DETERMINATION OF SURFACE TEMPERATURE

The retrieval of surface-equivalent blackbody temperature for each grid block was attempted by an analysis of the frequency distribution of 50 radiance values within the block and from the estimate of cloud amount, as described above.

Analysis of the infrared data reduces to identifying certain infrared histogram types; thus, a valid decision concerning surface temperature data can be made. Clear and mostly cloudy grid blocks can be determined readily from the analysis of visual data. Even though analyses of partly cloudy grid blocks sometime contain valid surface temperature data, these data are much more difficult to analyze. This difficulty arises because the distributions of cloud amount, type, and patterns are virtually infinite in nature. As a result, a whole host of infrared histograms is evident from a given target size when clouds are viewed from satellite altitude.

The Pearson System (1894) of distribution classification is used to identify frequency distribution shapes for interpretation of the infrared data with grid blocks. Standard deviation, skewness, and kurtosis are computed for the sample of 50 discrete measures of infrared values in the grid block. The σ ,

$\sqrt{b_1}$, and b_2 give an interpretation of the shape of the frequency distribution of the 50 values. Surface temperature retrieval decisions are made from this information as follows. All grid blocks containing 40 percent or more estimated cloud cover, as determined from the visual data within that block, were eliminated. The effect of cloud and cloud edges does not permit accurate retrieval with blocks containing 40 percent or more cloud cover. For grid blocks less than 40 percent cloud cover and standard deviations less than 2.0 counts values, the mode count value of the distribution is considered most representative of the surface value. For all other grid blocks, infrared distribution's position on the Pearson β_1, β_2 plane (Pearson and Hartley, 1972) was determined. Only those distributions indicative of surface view were then analyzed for warm mode values. In this study, warm modes of frequency distributions of partly cloudy scenes are considered surface-emitted radiances. Thus, using this frequency distribution classification technique, it is possible to automatically retrieve only surface values.

BLENDING SURFACE AND AIR TEMPERATURE FIELDS

In order to obtain a better spatial estimate of air temperature over the study area, the gradient field of equivalent blackbody surface temperatures is assumed to represent the gradient field of air temperature. The more dense measures of surface temperature and the relatively sparse measures of air temperature are then blended together to achieve a better estimate of air temperature over the field. This blending technique is described by Holl and Mendenhall (1971). Fields of data are blended by defining an error function that expresses the inconsistency between a gradient field and a measured field, and generating a new field that minimizes the error function over the whole field.

Successfully retrieved surface temperature from the grid blocks are placed in the center of the grid block and considered representative of that block. A grid mesh of 21x23 is placed over the study area. Surface temperature values at each of the 483 grid intersections are computed by weighting nearby surface temperature observations, based on their respective distances to the grid intersection point. The NWS air temperatures were analyzed in this same manner. The gradient of the SMS surface temperature field is then determined at each point in the grid mesh and blended into the NWS air temperature at that point to get a new value. Thus, gradients of the SMS surface temperature field are reflected in the NWS air temperature analysis field.

ESTIMATED AND FIRE DANGER STATION 1-HR TLFM

The 1-HR TLFM estimate value is computed at each of the 483 grid points using SMS-blended air temperature, relative humidity from an estimated field taken from NWS observations, and cloud amount from that estimated by the visible data from SMS. Air temperature, humidity, and cloud amount, as observed by the 34 fire danger stations at 1300 LST, are placed at their respective locations in the study area. These data are then interpolated and weighted to the 21x23 grid mesh.

RESULTS AND DISCUSSIONS

If one considers the 21x23 grid mesh intersection points as a distribution of the 1-HR TLFM from the study area, then computed and estimated fields can be compared along with the differences between the fields. Table 1 compares these fields for the days selected.

Table 1.--Distribution statistics for calculated, estimated, and difference fields for 1-HR TLFM for 1300 EST of January 2, 5, 14, 15, 16, 1975.

Date	Distribution	\bar{X}	σ	Max	Min	$\sqrt{b_1}$	b_2	n
2	Calculated	5.47	0.90	10.2	3.3	2.92	12.13	483
	Estimated	4.78	1.07	10.2	3.7	1.45	5.65	483
	Difference	-.70	0.94	3.0	-5.9	-.27	8.57	483
5	Calculated	8.88	1.57	14.9	6.2	0.73	3.39	483
	Estimated	8.20	1.67	17.0	5.9	1.04	4.68	483
	Difference	-.68	1.22	5.7	-5.2	-.02	7.08	483
14	Calculated	6.63	0.96	10.9	4.4	1.17	5.60	483
	Estimated	5.96	0.56	7.6	4.7	0.15	3.01	483
	Difference	-.66	0.96	1.1	-4.7	-.94	4.29	483
15	Calculated	6.30	0.30	10.2	4.4	0.94	4.96	483
	Estimated	5.78	0.47	7.4	4.6	0.18	3.04	483
	Difference	-.52	0.67	2.1	-3.9	-.71	7.49	483
16	Calculated	6.61	1.63	11.4	4.0	0.91	3.42	483
	Estimated	6.22	1.20	10.5	4.7	1.90	6.32	483
	Difference	-.38	1.20	3.0	-4.1	-.25	3.28	483

Table 1 indicates that the estimated and computed fields are in good agreement. Since data from the SMS are available half-hourly and surface observations from NWS observations are available from NMC hourly, estimates of 1-HR TLFM could be made. A more detailed analysis of mapped hourly 1-HR TLFM distribution for this period can be found elsewhere (Waters, 1975).

Data from the SMS has been blended with surface meteorological data to estimate a component in the NFDRS. Results indicate generally good agreement. At the time this study was conducted, data had to be collected on magnetic tape and processed later after earth location. Today, automated earth-location techniques, used operationally, are accurate to about 10 km or better. Digital data from the SMS/GOES are now earth located and ingested into disk making the data available near real time. Only specific sequences of SMS/GOES data are now being ingested for an area 50°N to 18°S and 25°W to 135°W. Disk space has been made available to ingest all SMS/GOES thermal infrared (some visible also) digital data at reduced resolution (9 km). Techniques to automatically process the digital data for time sequence scene differences are now being developed at NESS.

The real value of the SMS/GOES data might not be that it can be molded to a conventional measure of fire danger assessment, but that some new product such as scene change temperature, cumulative cloud cover, or surface temperature change will be found not only practical but economical to produce. It is technically feasible to produce such products today since the NESS IBM 360/195 computer containing the VISSR real time data is connected to the NWS IBM 360/40 computer containing the surface observation data files. In addition to these data are the forecast fields produced by NMC. This author knows of no work within the U.S. Department of Agriculture, NWS, or NESS to develop such an automated product.

REFERENCES

- Bristor, C. L. (Editor)
1975. Central processing and analysis of geostationary satellite data. U.S. Dept. of Commerce, NOAA Technical Memorandum NESS 64, Washington, D.C., 155 p.
- Deeming, J. E., J. W. Lancaster, M. A. Fosberg, R. W. Furman, and M. J. Schroeder.
1972. National fire danger rating system. USDA Forest Service Research Paper, RM-84, 165 pp.
- Fosberg, M. A. and J. E. Deeming.
1971. Deviation of the 1- and 10-hour timelag fuel moisture calculations for fire-danger rating. USDA Forest Service Research Note, RM-207, 8 pp.
- Helfman, R.
1974. AFFIRMS User's Manual. Pacific Southwest Forest and Range Experiment Station, Berkley, California.
- Holl, M. M. and B. R. Mendenhall.
1971. Fields by information blending: sea-level pressure version. Fleet Numerical Weather Center, Final Report Project M-167, Monterey, California, 65 pp.
- Miller, D. B.
1971. Global atlas of relative cloud cover 1967-70 based on data from meteorological satellites. U.S. Dept. of Commerce and U.S. Air Force Joint Publication, Washington, D.C., 237 pp.
- Pearson, E. S. and H. O. Hartley (Editors).
1972. Biometrika tables for statisticians Vol. II. Cambridge University Press, London, England, 385 pp.
- Pearson, K.
1894. Contributions to the mathematical study of evolution. Philosophical Transactions of the Royal Society of London, Series A, pp. 71-110.
- Waters, M. P.
1975. Estimation of 1-hour timelag fuel moisture with surface and synchronous meteorological satellite data. Ph.D. Dissertation, School of Forest Resources, University of Georgia, Athens, Georgia, 176 pp.

Analysis of Colorado Mountain Fire Weather¹

Jack D. Cohen^{2/}

Abstract.--Surface data from fire weather stations were used to calculate ninetieth percentile Burning Indices and defined as critical fire weather. High correlations were found between the occurrence of dry-wind conditions and the severity of critical fire weather. A synoptic 500 mb examination indicated a general trend for certain patterns to accompany regional winds. Analysis of gravity wave potential through the Scorer number indicated that high surface winds can be accompanied by moderate 500 mb winds with decreased atmospheric stability.

INTRODUCTION

Colorado is experiencing population increases, particularly in and adjacent to the east slope metropolitan areas. The increase in population is also being felt in the forested mountain areas by means of permanent residences, resorts and short-term visitation such as weekend camping and hunting in the autumn. Although in other regions, the increased investments and use has created a potential for destructive fire occurrences.

Land management plans have come into being in response to the increased utilization of Colorado mountain areas. To provide for a complete land management plan, the potential destruction from wildfire should be considered. Such planning would indicate high hazard areas and thus help to avert high investment losses and possible loss of life. An analysis of the meteorology and climatology is essential for assessing the potential for the occurrence of a destructive wildfire.

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GENERAL METHODS

Data for the analysis were acquired from the Forest Service for Colorado fire weather stations. Only those stations with at least 8 years of historical records were chosen. Figure 1 gives a list and distribution of the fire weather stations. All of the surface analysis was done using these weather stations. Synoptic maps and Grand Junction upper-air data were acquired from the Daily Weather Map series (U.S. Dep. of Commerce) and the Northern Hemisphere Data Tabulations (U.S. Dep. of Commerce).

Surface data from fire weather stations were used to calculate National Fire Danger Rating System (NFDRS) (Deeming and others 1972) Burning Index (BI) values by means of FIRDAT (Furman and Helfman 1973). The NFDRS fuel models used for the BI calculations were the same for the stations as those used by the regional dispatcher. The BI was selected as an indicator of the relative severity of fire weather because of its comprehensive integration of the System's weather inputs.

A ninetieth percentile Burning Index level was calculated for the historical record of each selected weather station. Those BI values above the ninetieth percentile level were considered indicative of severe weather conditions for their respective station and defined as critical fire weather.

The occurrence of low relative humidities and high windspeeds (dry-wind conditions) were tabulated from the historical record for each station. From this tabulation, a percent occurrence of the dry-wind conditions was found during a time experiencing a BI above the

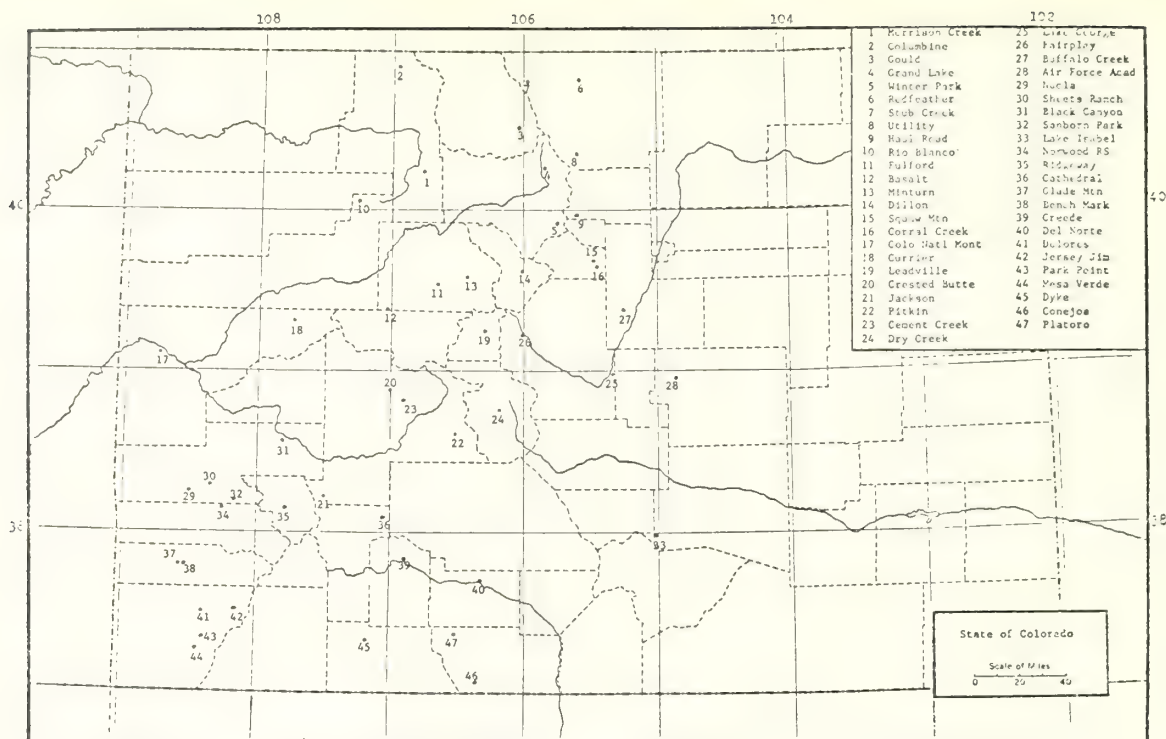


Figure 1.--Colorado station location map.

ninetieth percentile level.

Those periods experiencing critical fire weather (ninetieth percentile BI) were analyzed for their accompanying synoptic patterns. The general flow was characterized using the 500 mb level. Grand Junction upper-air data (1200 Z) were analyzed for the period May through September 1968 for recurring gravity wave characteristics accompanying windy conditions experienced at Colorado fire weather stations.

ANALYSIS AND RESULTS

The ninetieth percentile boundary BI values for the selected fire weather stations were stratified according to the station's NFDRS fuel model. The BI values were ranked from highest to lowest and three relative severity levels were assigned to the ranking (high, medium, and low). This procedure normalized the BI values between the different fuel models. The BI boundary value with its respective severity ranking is shown in figure 2. Also plotted on the map are fire climate-fire weather forecast zones based on equilibrium moisture content (e.m.c.) (Fosberg and Furman 1973). The BI severity varies greatly within each e.m.c. climatic zone. This does not contradict the placement of the

e.m.c. climatic zones; rather, it indicates that fuel moisture does not dominate in determining the severity of the ninetieth percentile BI in Colorado mountain areas.

Dry-wind conditions were chosen to be tested for their contribution to the ninetieth percentile BI severities. The conditions are as follow:

Relative Humidity	Windspeed
<20 percent	>7.5 meters/sec
<30, >20 percent	>10.0 meters/sec
<10 percent	>5.0, <7.5 m/sec

The dry-wind conditions were not chosen from severe weather that was experienced at the weather stations. These conditions will always increase the BI when entered as input into the NFDRS. However, high Burning Indices are not solely dependent on the occurrence of the conditions above. The fact that the dry-wind conditions are severe is obvious; their contribution to the ninetieth percentile BI severities and thus critical fire weather is not obvious.

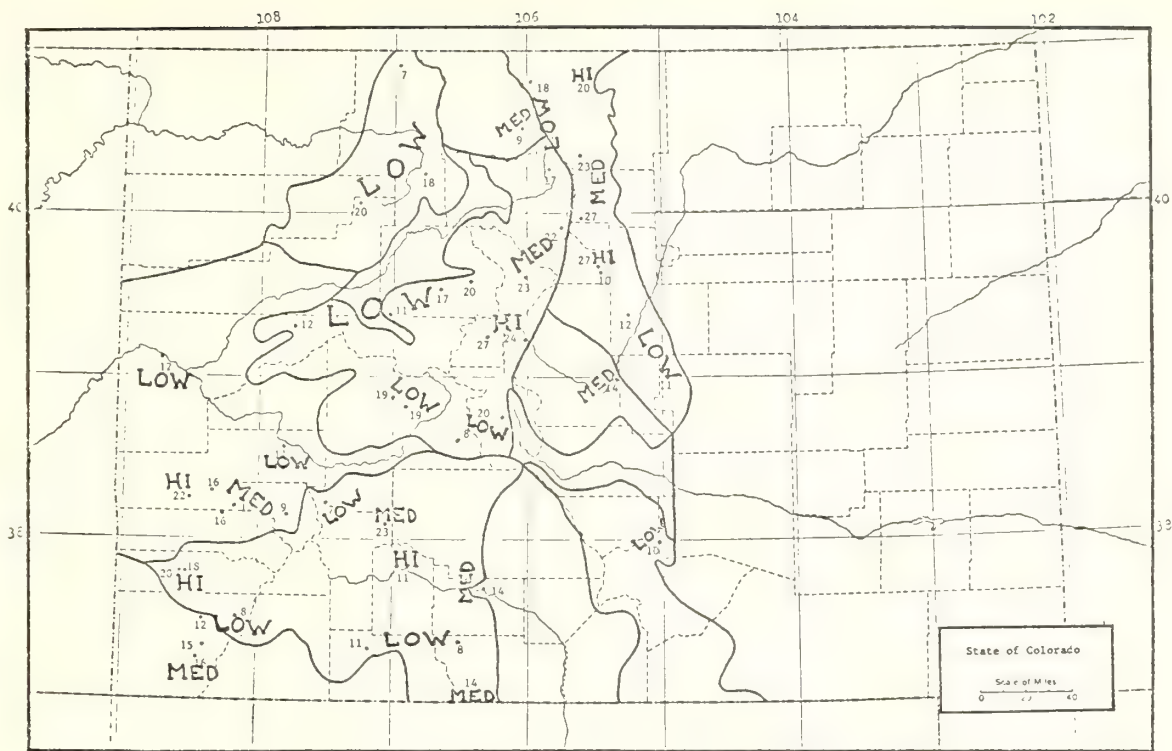


Figure 2.--Map of Colorado regional Burning Index severities with e.m.c. zones.

Table 1 lists, by representative fuel model, the ninetieth percentile BI boundary value with its respective percent dry-wind contribution. The ninetieth percentile BI boundary value was then correlated with the dry-wind percent contribution to critical fire weather, resulting in high correlation coefficients. This indicates that the severity of BI values in Colorado are dependent on dry-wind conditions. This characterizes Colorado critical fire weather as a dry-wind phenomenon.

The establishment of the dependence of critical fire weather in Colorado on dry-wind conditions was followed by an examination of the relative importance of each component (low relative humidity and high windspeed). Frequencies of occurrence for relative humidity intervals and windspeed intervals were plotted on a map with the relative BI severities. Relative humidity frequencies did not correspond spatially with the distribution of BI severities. This should not be surprising since fuel moisture was shown not to be indicative of ninetieth percentile BI severities through the comparison with e.m.c. zones. Windspeed frequency of occurrence did correspond to the distribution of BI severities. Figure 3 illustrates the association of high windspeed frequencies with those areas having high severity ninetieth percentile BI's. It

Table 1.--Critical Burning Index with percent wind contribution

Fuel Model C			Fuel Model G		
Station	90% BI	% Dry-wind	Station	90% BI	% Dry-wind
Nucla	22	92.5	Haul Road	27	62.3
Redfeather	20	79.9	Squaw Mtn	27	61.2
Glade Mtn	20	66.3	Leadville	27	53.4
Bench Mark	18	73.1	Fairplay	24	39.3
Sheets Ranch	16	31.6	Utility	23	17.0
Norwood	16	49.6	Cathedral	23	24.5
Mesa Verde	16	26.8	Dillon	23	8.3
Park Point	15	13.8	Winter Park	22	13.4
Lake George	14	32.5	Rio Blanco	20	5.3
Del Norte	14	30.6	Minturn	20	3.6
Conejos	14	24.6	Dry Creek	20	15.4
Buffalo Crk	12	7.8	Crested Butte	19	4.5
Colo Natl Mont	12	16.1	Cement Creek	19	8.5
Sanborn Park	12	23.9	Morrison Crk	18	0.0
Dolores	12	3.4	Stub Creek	18	0.0
Currier	12	2.9	Fulford	17	6.4
Air Force Acad	11	8.2	Grand Lake	17	1.3
Black Canyon	11	4.1			
Dyke	11	2.2			
Rasalt	11	8.3			
Lake Isabel	10	6.4			

(90% BI - % Dry-wind correlation)
r = .91

(90% BI - % Dry-wind correlation)
r = .94

Fuel Model H

Station	90% BI	% Dry-wind
Creede	11	45.7
Corral Creek	10	30.3
Gould	9	8.6
Ridgeway	8	6.8
Jersey Jim	8	5.1
Platoro	8	7.8
Pitkin	8	9.1
Columbine	7	0.0
Jackson	7	0.0

(90% BI - % Dry-wind correlation)
r = .94

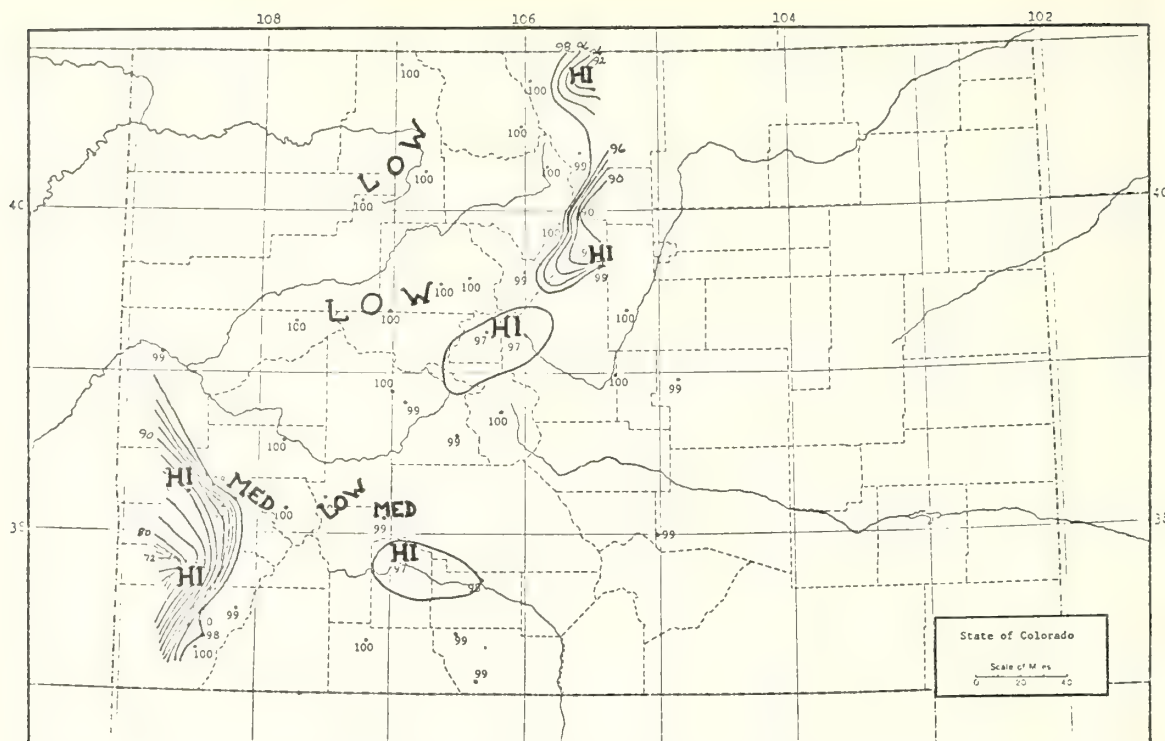


Figure 3.--Comparison of wind frequency and critical BI severity in Colorado (wind, 10 m/s; contour interval, 2 percent; HI, MED, LOW refer to severity of BI).

should be noted that the areas of high severity also experience relatively high frequencies of low relative humidities. This is not a contradiction. Several areas having relatively high frequencies of low relative humidities, but experiencing little wind, possessed low severity BI's.

The examination of surface winds in relation to critical fire weather also indicated regional tendencies for windiness. The windy areas on the west slope and east slope of the mountains (shown in fig. 3) did not experience high wind conditions simultaneously. Synoptic, 500 mb level patterns were examined for each occurrence of a wind, 10 meters per second or greater, with an accompanying relative humidity less than or equal to 20 percent. Low relative humidity criteria were included to help filter out convective storm activity. Composite maps were drawn up to represent the generalized 500 mb level patterns that accompany high wind-low relative humidity conditions at the fire weather stations.

Figures 4 and 5 depict the generalized 500 mb patterns that accompany high winds along the northern Front Range. These patterns are characterized by anti-cyclonic curvature over Colorado, producing rising barometric

pressure and generally clear skies. Usually these winds do not extend south over the entire state, but when they do, high mountain stations will experience high wind conditions. High winds in the mountains on the west slope are usually accompanied by cyclonic circulations and decreasing barometric pressure. Figures 6 and 7 depict winds accompanied by low pressure systems to the west of Colorado. The direction of the wind in the southwest quadrant is dependent on the north-south location of the trough. Figure 8 depicts southwesterly winds accompanied by a ridge over the midwest.

One prominent exception to the above descriptions was evident during the pattern analysis. Several high wind situations at many of the stations were not accompanied by significant 500 mb winds. The 500 mb patterns were not generally well defined and exhibited windspeeds as in figure 8. The influence of atmospheric stability on surface winds was examined by a general gravity wave characterization.

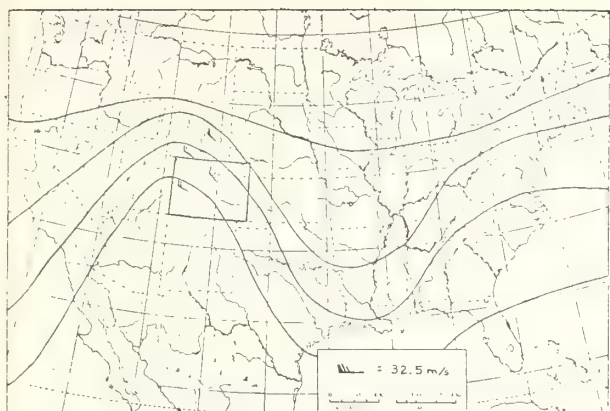


Figure 4.--

500 mb maps of patterns associated with high winds in northern Colorado.

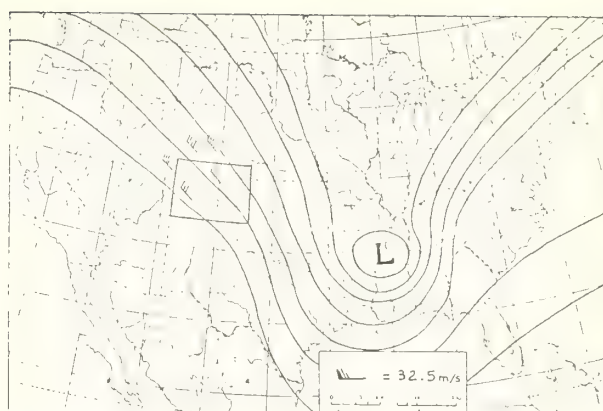


Figure 5.--

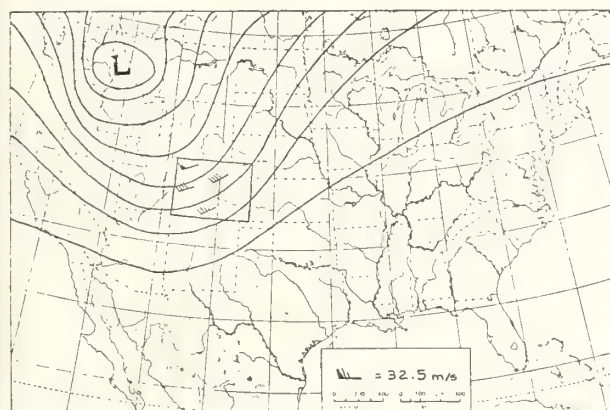


Figure 6.--

500 mb maps of patterns associated with high winds in west-slope mountains of Colorado.

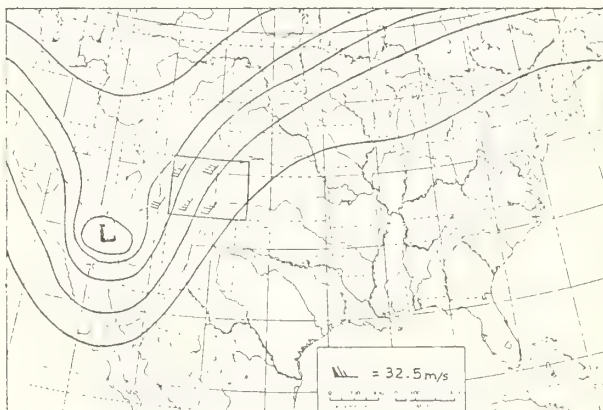


Figure 7.--

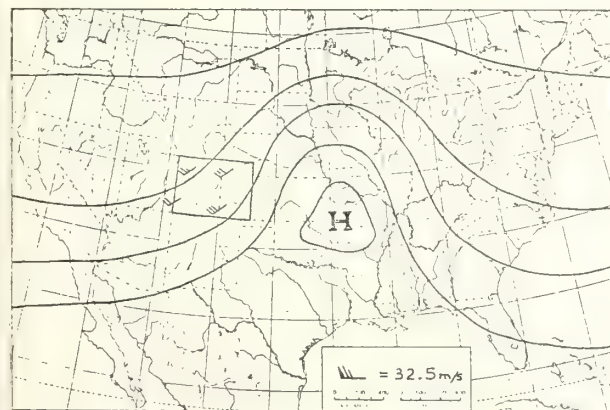


Figure 8.--500 mb map of pattern associated with high winds in west-slope mountains of Colorado.

Grand Junction upper-air data were analyzed for its general gravity wave character using Scorer's wave number (Scorer 1967):

$$\ell = \sqrt{\frac{g/\theta \frac{\delta\theta}{\delta z}}{u^2}}$$

where

ℓ = wave number (m^{-1})

θ = potential temperature ($^{\circ} K$)

z = height (m)

u = wind velocity (m/sec)

g = acceleration due to gravity (m/sec^2).

Calculations were made using this modified finite form:

$$\ell^2 = \frac{g/\bar{\theta} \frac{\Delta\theta}{\Delta z}}{u^2}$$

where

ℓ = (wave no.)² for the atmosphere between 700 mb and 300 mb

$\bar{\theta}$ = average potential temperature between 700 mb and 300 mb

$\Delta\theta$ = potential temperature difference between 700 mb and 300 mb

Δz = height difference between 700 mb and 300 mb

u = 500 mb windspeed.

The equation (ℓ^2) behaves as follows:

ℓ^2 is inversely proportional to the windspeed; if the atmosphere becomes stable;

$\frac{\Delta\theta}{\Delta z}$ increases, thus increasing ℓ^2 .

As the atmosphere becomes less stable,

$\frac{\Delta\theta}{\Delta z}$ decreases, thus decreasing ℓ^2 .

At neutral stability, $\frac{\Delta\theta}{\Delta z} = 0$, $\ell^2 = 0$.

As ℓ^2 increases, wavelengths decrease causing less disturbance to other portions of the atmosphere. Momentum is usually not transferred to the ground. As ℓ^2 decreases, wavelengths increase, increasing the possibility of a momentum transfer to the ground.

An ℓ^2 value was calculated for each 1200 Z sounding from June through September 1968. The dry-wind classes previously defined, excluding windspeeds less than 7.5 meters/sec, were used to determine the occurrence of a high wind at any of the fire weather stations for each day.

The occurrences of ℓ^2 values are plotted with the high wind occurrences in figure 9. This figure indicates an important relation between high wind occurrence and ℓ^2 values between 1.0×10^{-7} and 5.0×10^{-7} . The high wind occurrences are not surprising when ℓ^2 is in this interval because high winds at 500 mb contribute to a low ℓ^2 . However, 5

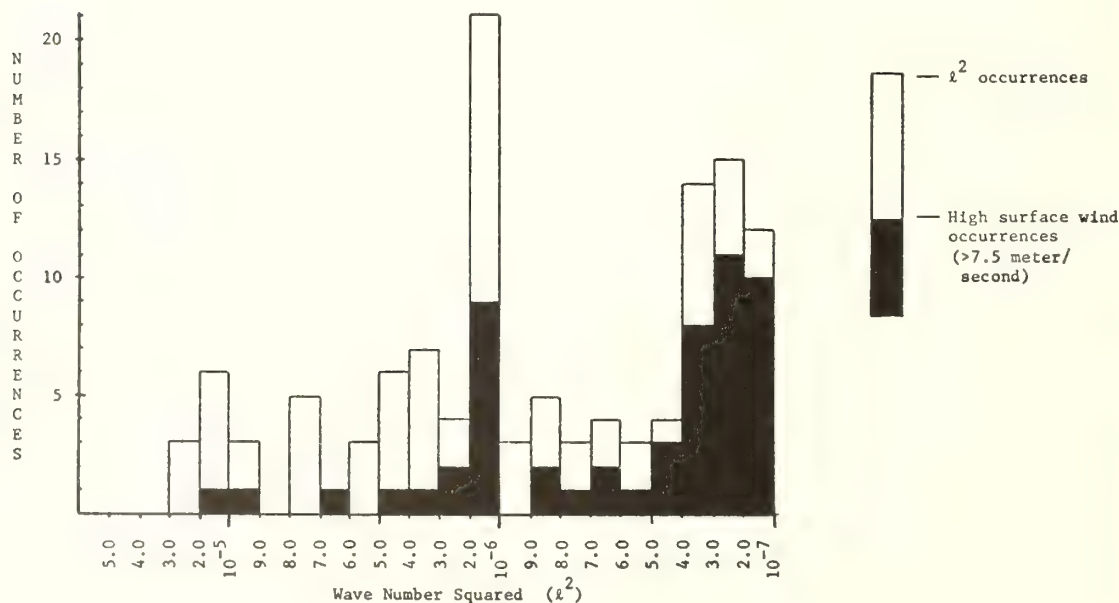


Figure 9.-- ℓ^2 interval occurrences with the occurrence of high surface winds by ℓ^2 interval.

out of 19 high wind occurrences with ℓ^2 values between 2.0×10^{-7} and 4.0×10^{-7} were accompanied by moderate 500 mb winds (12.5 meters/sec). In these cases, a decrease in stability resulted in low ℓ^2 values, longer wavelengths, and accompanying high surface winds.

SUMMARY AND CONCLUSIONS

The ninetieth percentile BI level was calculated from the historical record for each station and defined as critical fire weather for that station. The stations were ranked according to their relative severity of ninetieth percentile BI and compared with their respective equilibrium moisture content (e.m.c.) zones. A lack of correspondence indicated that the ninetieth percentile BI severity was not highly dependent on fuel moisture.

Dry-wind conditions were defined and their frequency of occurrence found to be highly correlated to the ninetieth percentile BI severity. The regional distribution of dry-wind occurrences corresponded with the ninetieth percentile BI severity distribution. The distribution of high wind occurrences also corresponded with the relative severities of the ninetieth percentile BI, thus indicating the importance of wind in producing critical conditions in Colorado.

The 500 mb pattern examination indicated that east slope winds are generally accompanied by flows north of west, whereas west slope winds are generally accompanied by flows south of west. Usually the high surface winds were accompanied by well developed 500 mb patterns and strong input winds. However, in several cases, strong

surface winds were accompanied by only moderate 500 mb winds and poorly defined patterns.

Examination of the data from one season, using Scorer's wave equation, indicated that in several cases a long wave character can be induced through less stable conditions and moderate winds. This tends to explain how high surface winds can be experienced from only moderate winds aloft.

LITERATURE CITED

- Deeming, John E., James W. Lancaster, Michael A. Fosberg, and others.
1972. National fire-danger rating system. USDA For. Serv. Res. Pap. RM-84, 165 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.
- Fosberg, M. A., and R. W. Furman.
1973. Fire climates in the Southwest. Agric. Meteorol. 12:27-34.
- Furman, R. W., and R. S. Helfman.
1973. A computer program for processing historic fire weather data for the national fire-danger rating system. USDA For. Serv. Res. Note RM-234. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.
- Scorer, R. S.
1967. Causes and consequences of standing waves. Colo. State Univ. Dep. Atmos. Sci. Pap. 122, p. 75-95. Fort Collins, Colo.
- U.S. Department of Commerce.
[n.d.] Daily weather map (1964 through 1974). Environ. Sci. Serv. Adm., Washington, D.C.
- U.S. Department of Commerce.
[n.d.] Northern hemisphere data tabulations, synoptic weather maps, part II (1964 through 1971). Environ. Sci. Serv. Adm., Washington, D.C.

Synoptic Study of the Meteorological Conditions Associated with Extreme Wildland Fire Behavior¹

Edward A. Brotak and William E. Reifsnyder^{2/}

Abstract.--Fifty-two major wildland fires in the eastern half of the United States were analyzed to determine the synoptic situations involved. At the surface, 3/4 of the fires were found near frontal areas. The vast majority of fires were associated with the eastern portion of small amplitude but intense short wave troughs at 500 mb. A lack of moisture advection at 850 mb prohibits precipitation which normally accompanies these systems. This lack of precipitation in association with strong low-level winds found in these regions produces dangerous fire conditions at the surface. Such situations are shown to occur rarely.

INTRODUCTION

A small percentage of all wildland fires become major fires and are responsible for many of the lives lost and most of the resource damage. Besides favorable fuel moisture conditions, certain infrequent combinations of surface weather conditions are a prerequisite on the day of the fire. The major objective of this research is to determine the synoptic weather situations associated with these fires. In this study, we have determined the upper-air conditions that appear to be necessary for the development of large (>5000 acres) wildland fires in the eastern portion of the United States.

A review of the literature indicated that major fires were often associated with surface frontal areas. Such fires were reported both ahead of and behind cold fronts by Bond, *et al.* (1967), DeCoste, *et al.* (1968), Luke (1971), Miller (1972), Sando and Haines (1972), Sullivan (1966), and Wade and Ward (1973). Only a few researchers examined the upper air conditions and, of these, Bond *et al.* (1967), Finklin (1973), and Pirsko *et al.* (1965), noted an upper trough over the surface fire area. It

should be noted here that in the past most researchers have only examined one fire and its attendant situation. We believe that the present study is the first attempt to analyze comprehensively the synoptic patterns associated with a large number of fires widely separated in time and space. Schroeder (1964) did an extensive study in this area, but he dealt mainly with air mass type and only with periods of high fire danger, not actual fire occurrences.

DATA

Fire data were provided by the state fire officials and consisted of all fires burning 5,000 acres or more in the eastern half of the United States from 1963-1973 (See Table 1 and Figure 1). Information for each fire included the dates of fire start and control, location, and acreage burned. Of particular concern were major fire runs, periods of time when the fire was probably uncontrollable due to the prevailing weather conditions.

Weather maps for these periods were provided by the National Climatic Center in Asheville, North Carolina. Surface maps were available every three hours for the fire period. Morning and evening standard pressure level maps at 850 and 500 mb (~ 1500 and ~5000 m respectively) were also available.

^{1/}Paper presented at the Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, Nov. 16-18, 1976.

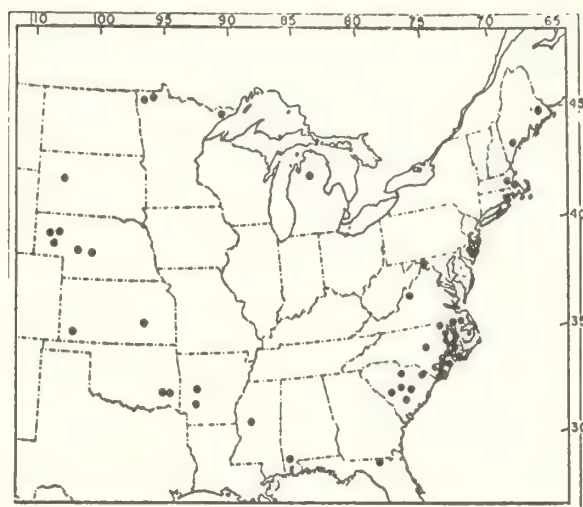
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Acknowledgements.--Research support by the Atmospheric Sciences Section N.S.F.

Table 1.--List of all fires analyzed.

Date	Location	Acreage Burned
3/25/63	Oklahoma	14,200
4/4/63	North Carolina	23,200
4/4-5/63	North Carolina	15,300
4/4-5/63	North Carolina	13,900
4/4-5/18/63	North Carolina	37,000
4/4/63	North Carolina	44,200
4/4-5/63	North Carolina	7,100
4/4-5/63	North Carolina	6,200
4/20/63	New Jersey	76,000
4/20/63	New Jersey	14,000
4/20/63	New Jersey	11,300
4/20/63	New Jersey	33,400
4/20/63	New Jersey	12,800
4/20/63	New Jersey	14,500
4/20-21/63	West Virginia	6,600
4/23-26/63	North Carolina	26,500
10/30/63	Arkansas	13,700
3/15/64	Oklahoma	7,200
5/23-25/64	Massachusetts	5,500
9/17-24/64	New Jersey	5,200
4/13/65	North Carolina	5,000
5/5/65	Nebraska	20,000
8/4-8/65	Maine	12,100
12/5-10/65	Arkansas	6,000
3/31-4/3/66	South Carolina	8,300
4/1-2/66	South Carolina	7,400
4/1/66	South Carolina	5,100
4/1-4/66	South Carolina	6,000
4/1-10/66	North Carolina	5,800
4/1-5/66	North Carolina	17,000
4/2-6/66	South Carolina	5,500
4/1-7/67	North Carolina	9,400
4/2-4/67	North Carolina	5,100
4/3-4/67	North Carolina	8,000
4/18-21/67	South Carolina	6,000
5/8-13/69	North Carolina	14,700
2/9-10/70	Alabama	6,000
12/4-5/70	North Carolina	6,300
1/18/71	Nebraska	9,200
3/22-23/71	North Carolina	29,300
4/12-15/71	North Carolina	5,800
4/18/71	New Jersey	21,000
4/18-21/71	North Carolina	14,400
5/14-16/71	Minnesota	14,600
2/26/72	Nebraska	7,200
2/28/72	Nebraska	5,600
3/6-7/72	Nebraska	120,000
3/6-7/72	Kansas	8,500
3/19/72	Kansas	9,000
4/16-18/72	North Carolina	18,500
4/11-13/73	Minnesota	7,700
4/12-15/73	Minnesota	9,200

Figure 1.--Location of all fires.



ANALYSIS

Surface Synoptic Situation

The fire runs were categorized by surface synoptic situation and the results are shown in Table 2. The fires were located with respect to an idealized frontal system and plotted in Figure 2. As shown in Table 2, more than half of all fire runs occurred following the passage of a dry cold front. Most runs occurred in the southeastern section of the frontal region (fig. 2). It is apparent that this is the primary region in which the proper combination of wind, moisture, temperature, and fuel conditions are found to produce large-fire conditions in the eastern half of the United States.

One-quarter of the runs occurred prior to the passage of a cold front. Often a fire would make a run both ahead of and behind the front. Thus, three-quarters of the fire runs were frontal situations.

Twelve percent of the fire runs occurred in the warm sector of a low pressure area. There were two different types of low pressure areas involved with major fires. One was the Rocky Mountain low which produced dangerous fire conditions in the Plains and Midwest states. The other kind of low was a storm which moved easterly through southern Canada producing dangerous fire conditions in the Great Lakes states and in northern New England. Major lows in the eastern United States are almost always accompanied by precipitation.

Of the remaining fire runs, 5% occurred in the warm sector of a high pressure area far from any fronts or low pressure areas. Usually, these were continental tropical air masses with very high temperatures and extremely low

humidities. Four fire runs occurred with other synoptic situations.

Table 2.--Percentage of fire runs by synoptic situation.

Synoptic situation	# of runs	%
Following cold frontal passage (CFA) ¹	45	54
Prior to cold passage (CFB) ²	20	24
Warm sector of low (WSL) ³	10	12
Warm sector of high (WS) ⁴	4	5
Other	4	5

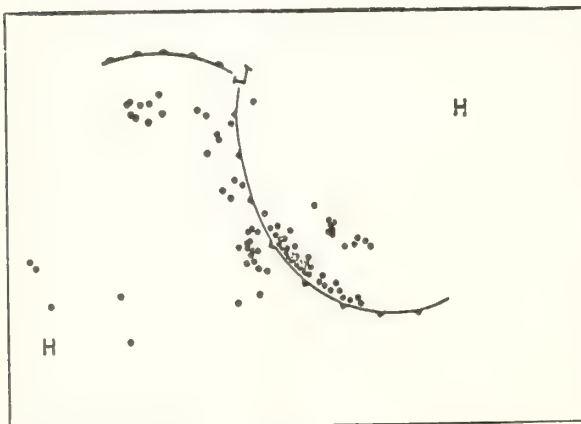
¹/CFA: Cold frontal passage in prior 24 hours, area not within closed cyclonic isobars.

²/CFB: Cold frontal passage occurred within 24 hours, area not within closed cyclonic isobars.

³/WSL: Area within closed cyclonic isobars with low pressure center to west, no cold frontal passage within 24 hours.

⁴/WS: Area within closed anti-cyclonic isobars with high pressure center to south or east, no cold frontal passage within 24 hours.

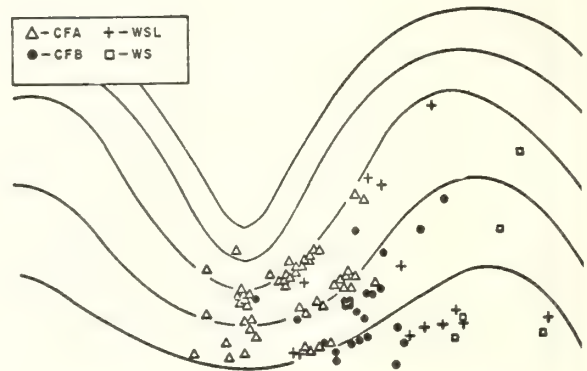
Figure 2.--Idealized surface map showing all fire runs.



500 mb Analysis

Figure 3 shows the location of the fire runs in relation to an idealized 500 mb (~5500 m) trough. The vast majority occurred in the southeastern portion of the trough. In most cases, small amplitude, intense, often fast-moving short wave troughs were involved. Usually the radius of curvature was small, 640 km or less. This great curvature induces more divergence aloft, thus intensifying the surface systems.

Figure 3.--Idealized 500 mb map showing all fire runs.



850 mb Moisture Advection

The analysis of the 500 mb flow patterns indicated that situations associated with major fires were similar to ones that usually produce precipitation and poor fire conditions. The reason for the lack of precipitation just prior to and during these extreme fire situations is very important in the overall understanding and especially for the prediction of extreme fire behavior. The precipitation process in the atmosphere has two components: There must be significant moisture in the air and there must be the dynamic process to produce condensation and precipitation. It appears that the dynamic processes occurred in many fire situations, so the atmospheric moisture content was examined.

A parameter often used in the routine forecasting of precipitation is moisture advection at 850 mb. If the dewpoint depression of the air at this level upwind of an area is 5°C or less, precipitation is likely if the synoptic situation favors it. Moisture advection at 850 mb was then examined for all fire runs, and in 93% of all cases, it was insufficient to allow precipitation. Thus, this was seen as a major factor associated with the development of large fires.

Moisture advection depends primarily on wind flow patterns: A source of moisture must be available for moisture to be advected. For areas in the eastern United States, the two major sources of moisture are the Gulf of Mexico and the Atlantic Ocean. The lack of moisture advection at 850 mb for most fire runs was due to a basic westerly flow at this altitude. Flows with a more southerly or easterly trajectory were not favorable for fire runs.

The reason for this flow pattern at lower

levels can again be traced back to the upper-air flow patterns. It was mentioned that the majority of upper-level troughs involved with extreme fire behavior were of small amplitude. Often, the trough was centered in Canada, but the lack of latitudinal extent prohibited the development of a long southerly flow which would pull up moisture from the Gulf of Mexico. The surface reflection of this upper-air flow is that the cold front often moves in from the north or northwest rather than west.

Frequency of Upper-Level Trough Passages

The association of major fires and upper-level trough occurrences would be meaningless if such occurrences happened every day. To determine a normal frequency of trough passages, two years were examined. The first year, 1973, produced ample precipitation over the eastern half of the United States especially in the spring, and only two major fires in Minnesota were reported. The second year, 1963, was noted for the drought along the East Coast and resultant fires in the spring.

Table 3 shows that in 1973, there were 89 upper trough passages, or about one every four days. In 1963, a drought year, there were 87; so the frequency was the same. Of greater importance is the passage of upper troughs without precipitation. These are the situations which were associated with most of the extreme fire occurrences. Such situations are very rare. Only five cases occurred in 1973. Surprisingly, only six cases occurred in 1963. Thus, the upper-air conditions seen associated with major fires in this study, i.e. dry trough passages, occur infrequently.

Table 3.--Frequency of upper-level trough passages.

	1963	1973
Total trough passages:	87	89
Total trough passages March-May:	21	25
Total trough passages without precip.:	6	5
Total trough passages without precip. March-May:	4	0

Related Surface Conditions

The synoptic situations discussed above are related to certain surface weather conditions which are characteristic of dangerous fire weather. The lack of precipitation is an obvious factor and has already been noted. The other prevalent factor was strong surface winds. Such winds were noted with almost all major fire occurrences.

SUMMARY

The occurrences of major fires in the eastern half of the United States have been related to certain specific synoptic situations. Most fires occurred near frontal areas, especially following the passage of a dry cold front. Such situations could be easily determined on surface maps and could be useful in forecasting.

Of even more importance to forecasting is the relationship between major fires and the upper-air situation. Major fires were associated with a specific type of 500 mb trough, an intense system of small latitudinal extent. Such troughs are associated with areas of strong winds but no precipitation at the surface, i.e. dangerous fire conditions. With the great accessibility of forecasts and high level of predictability of 500 mb, dangerous fire conditions could be reasonably forecast up to 72 hours in advance.

LITERATURE CITED

- Bond, H. G., K. MacKinnon and P. F. Noar.
1967. Report of the Meteorological Aspects of the Catastrophic Bushfires in Southeastern Tasmania on February 7, 1967. Bureau of Meteorology, Melbourne, Australia, 17 p.
- DeCoste, J. H., D. D. Wade, and J. E. Deeming.
1968. The Gaston Fire. U.S.D.A. Forest Service Research Paper SE-43, 36 p.
- Finklin, A. I.
1973. Meteorological Factors in the Sundance Fire Run. U.S.D.A. Forest Service General Technical Report INT-6, 46 p.
- Luke, R. H.
1961. A Report on Some Aspects of the "Dwellingup" Fire of January 1961. Fire Protection Office, Perth, Australia, 22 p.
- Miller, G. R.
1972. Mullen Fire: March 1972. Project Fire Weather Report, Central Region, Kansas City, Missouri, 6 p.
- Pirsko, A. L., L. Sergius, and C. Hickerson.
1965. Causes and Behavior of a Tornadoic Fire-Whirlwind. U.S.D.A. Forest Research Note PSW-61, 13 p.
- Sando, R. W., and D. A. Haines.
1972. Fire weather and behavior of the Little Sioux fire. U.S.D.A. Forest Service Research Paper NC-76, 6 p.
- Schroeder, M. J.
1964. Synoptic Weather Types Associated with Critical Fire Weather. Pacific Southwest Forest and Range Experiment Station, Berkeley, California, 492 p.
- Sullivan, W. G.
1966. The Plum Fire. Central Region Technical Memorandum 5, U.S. Weather Bureau, Kansas City, Missouri, 7 p.
- Wade, D. D. and D. E. Ward.
1973. An Analysis of the Air Force Bomb Range Fire. U.S.D.A. Forest Service Research Paper, SE-105, 38 p.

The Effect of Latitude and Season on Index Values in the 1977 NFDR System¹

Robert E. Burgan^{2/}

Abstract.--Seasonal changes in day length and solar radiation intensity at three latitudes influenced the Man-Caused Ignition Component, the Energy Release Component, and the Burning Index of the National Fire-Danger Rating System. Seasonal effects for the Energy Release Component are greatest in fuel models with heavy loadings of large, dead fuels. Day length has little effect on the Man-Caused Ignition Component, but solar radiation intensity produces a small effect through its influence on fuel temperature. Inclusion of rate-of-spread in Burning Index computations reduces these effects.

INTRODUCTION

Fire managers have suggested that the National Fire-Danger Rating (NFDR) System should include the effect of seasonal changes in day length and solar radiation intensity. This refinement does influence the fire-danger indexes and will be in the 1977 NFDR System.

Seasonal changes in day length and solar radiation differ considerably from southern to northern latitudes. During the 6 months of the year from May 1 to October 31, the maximum interval from sunrise to sunset, at 34° latitude, is 14 hours, 26 minutes; the minimum interval is 10 hours, 50 minutes. During the same 6-month period, the interval from sunrise to sunset at 65° latitude, varies from 22 hours, 3 minutes to 7 hours, 57 minutes. Assuming that 67 percent of the radiation received at the top of the atmosphere actually reaches the earth, the intensity of solar radiation received by the earth's surface at solar noon during the May 1-October 31 period ranges from 1.26 to 0.68 calories per square centimeter per minute at 35° latitude, and from 0.84 to 0.04 calories per square centimeter per minute at 65° latitude. These differences in day length and radiation intensity should produce rather large differences

in the NFDR indexes, particularly in the northern latitudes. However, the research reported here showed local weather modifies these effects to a great extent.

Weather data from three locations were used for the analysis: Lytle Creek Ranger Station at about 34° latitude in California's South Coast Drainage; Libby at 48° latitude in northwestern Montana; and Fairbanks Airport at 65° latitude in Alaska.

The NFDR indexes investigated were the Man-Caused Ignition Component (MCIC), an index proposed for the 1977 NFDR system, and related to the probability that a reportable fire will result if a "typical" man-caused firebrand encounters fine fuel; the Energy Release Component; and the Burning Index.

Fuel Model G, which has a high proportion of dead-to-live fuels, was used in the computations to generate these indexes.

MAN-CAUSED IGNITION COMPONENT

The MCIC is primarily dependent upon the moisture of fine fuels (1-hour timelag (1 HRTL) class fuels). These fuels consist of dead herbaceous plants and roundwood less than one-fourth inch in diameter. Also included is the uppermost layer of needles or leaves on the forest floor. Because this material responds so quickly to changes in temperature and relative humidity, its moisture content is influenced much more by the intensity of solar radiation at the basic observation time, than by long-term seasonal effects. The basic observation time is the time established to take the fire-danger observation which rates the day. It is generally in the early afternoon.

^{1/} Paper presented at the Society of American Foresters-American Meteorological Society Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, November 16-18, 1976.

^{2/} Research Forester, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, 507 25th Street, Ogden, Utah 84401. Located at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Montana.

MCIC values for the three locations were computed with radiation intensity values only for July 15, and compared with MCIC computations including radiation intensity calculated for each day in the study period. The results, for each of the three sample locations, are shown in figures 1, 2, and 3.

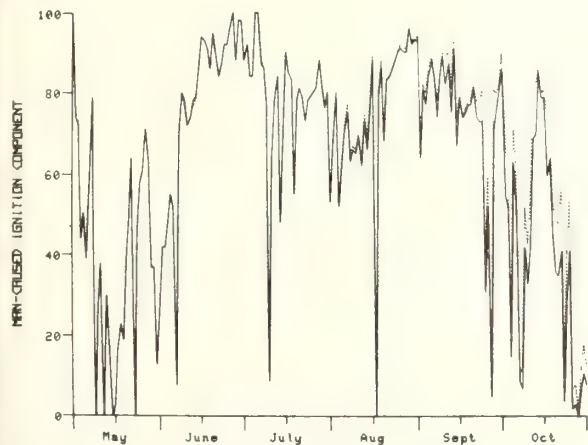


Figure 1.--Man-Caused Ignition Component computed for Lytle Creek (1974 data), with solar radiation intensity values for each day in the period (solid lines) and with intensity value for July 15 only (dotted lines).

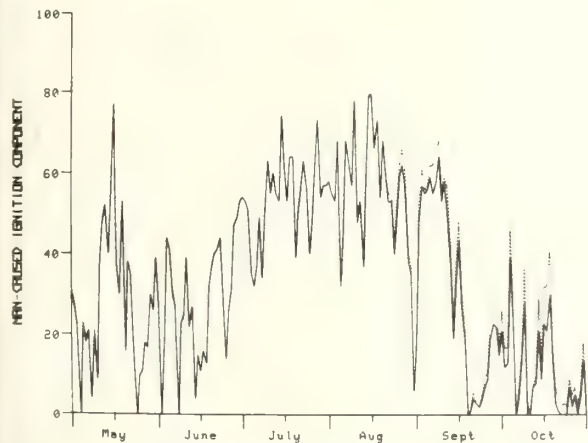


Figure 2.--Man-Caused Ignition Component computed for Libby (1973 data), with solar radiation intensity values for each day in the period (solid lines) and with intensity value for July 15 only (dotted lines).

The July 15 solar radiation intensity value becomes an increasingly poorer estimate of the actual value as one proceeds in time from that date. Thus, without the daily solar radiation correction, the MCIC becomes increasingly higher than it should in the fall portion of the fire season.

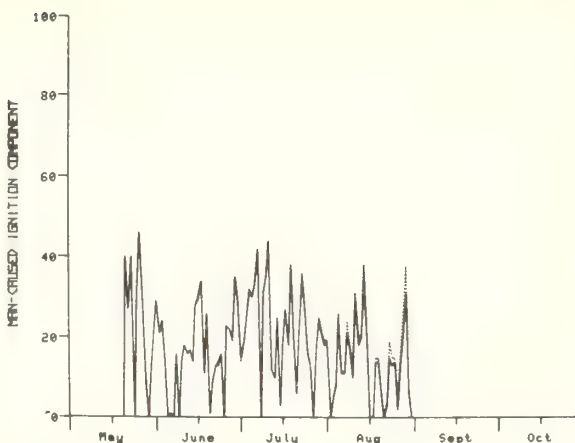


Figure 3.--Man-Caused Ignition Component computed for Fairbanks (1975 data) with solar radiation intensity values for each day in the period (solid lines) and with intensity value for July 15 only (dotted lines).

ENERGY RELEASE COMPONENT

Because the Energy Release Component of the NFDR is strongly influenced by larger fuels (100- and 1,000-HRTL classes), cumulative, seasonal weather effects on moisture contents become much more important than specific weather conditions at or near any particular basic observation time.

The moisture content of 100- and 1,000-HRTL fuels is a function of the equilibrium moisture content (EMC)^{3/} computed for early afternoon (maximum temperature-minimum relative humidity) conditions, early morning (maximum relative humidity-minimum temperature) conditions, and precipitation duration. Because the effect of precipitation duration is less than the effect of relative humidity during the fire season, the EMC exerts a strong influence on the moisture content of large, dead fuels.

EMC's were computed for both the early afternoon and early morning conditions, then either weighted equally (no day-length correction) or weighted proportionally to the hours of daylight (sunrise to sunset) and darkness for each day, to provide a day-length correction. For the computations in which day length varies, solar radiation intensity also varies.

^{3/} The moisture content that a fuel particle would attain if exposed for an infinite period in an environment of a specified constant temperature and humidity. When a fuel particle has reached its EMC, there is no net exchange of moisture between it and its environment.

Figures 4, 5, and 6 show the effect on the Energy Release Component for each of the three sample stations.

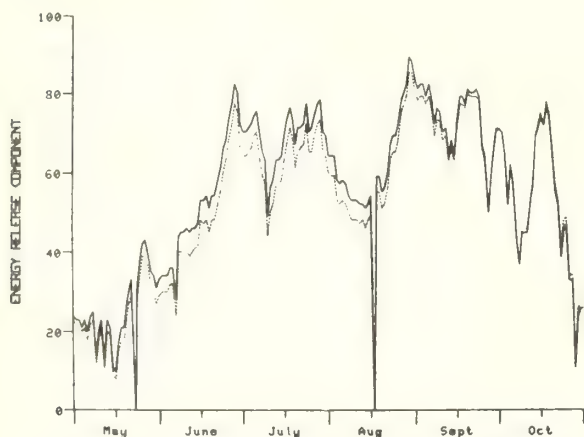


Figure 4.--Energy Release Component computed for Lytle Creek (1974 data) with a constant day-length value (dotted lines) and with variable day lengths (solid lines).

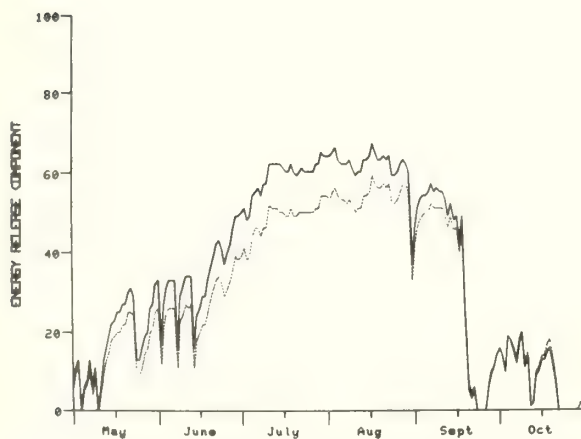


Figure 5.--Energy Release Component computed for Libby (1973 data) with a constant day-length value (dotted lines) and with variable day lengths (solid lines).

Due to the long summer day length in the northern latitudes, relative humidity recovery at night is much less than at more southerly latitudes. The daily weather data reflect this in that the EMC range calculated for Fairbanks (fig. 7) is much narrower than the EMC range calculated for either Lytle Creek or Libby (fig. 8 and 9). Burning conditions in Alaska often reflect this, with fires burning nearly as well at night as in the day.

Because the EMC range is so narrow in the northern latitudes, weighting the EMC by actual hours from daylight to dark does not

result in Energy Release Component values that are much different from those obtained using an equal weighting of 12 hours of daylight to 12 hours of dark.

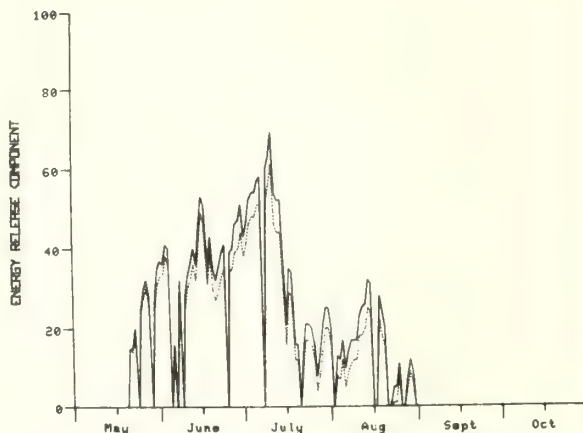


Figure 6.--Energy Release Component computed for Fairbanks (1975 data) with a constant day-length value (dotted lines) and with variable day lengths (solid lines).

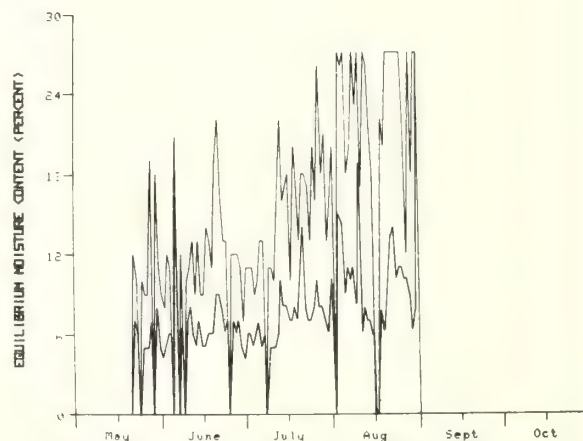


Figure 7.--Daily maximum and minimum equilibrium moisture content at Fairbanks (1975 data).

Figure 10 illustrates what the seasonal effect of day length would be on the Energy Release Component, if the weather data from Libby were assumed to have been observed at Fairbanks, (if the latitude of Libby were 65°). The large difference in the Energy Release Component, when computed with and without the appropriate day length correction for 65° latitude, occurs because the large day/night EMC range for Libby is combined with the large seasonal day length change at the latitude of Fairbanks.

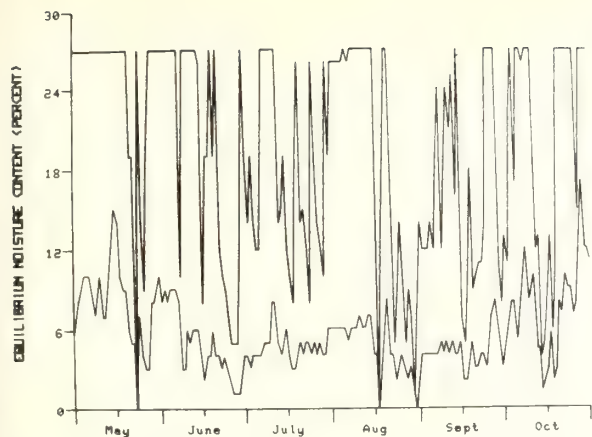


Figure 8.--Daily maximum and minimum equilibrium moisture content at Lytle Creek (1974 data).

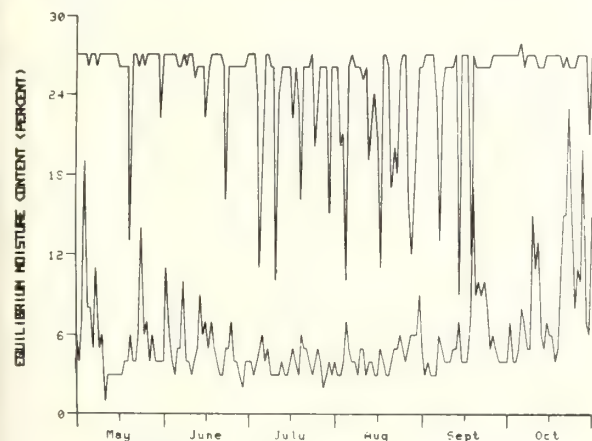


Figure 9.--Daily maximum and minimum equilibrium moisture content at Libby (1973 data).

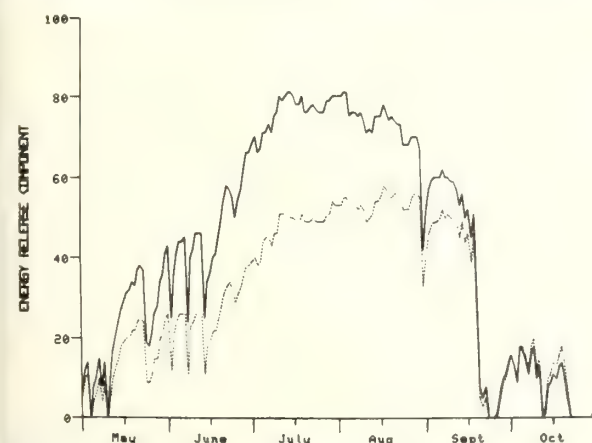


Figure 10.--Energy Release Component computed using 1973 weather data for Libby, with an assumed latitude of 65° with day-length correction (solid lines) and without the correction (dotted lines).

BURNING INDEX

The Burning Index is a normalized value of flame length, scaled to vary between 0 and 100. Figures 11, 12, and 13 show it is rather insensitive to seasonal changes in solar radiation intensity and day length. The reason for this lies in the parameters used to calculate the flame length--rate of spread, reaction intensity, and residence time.

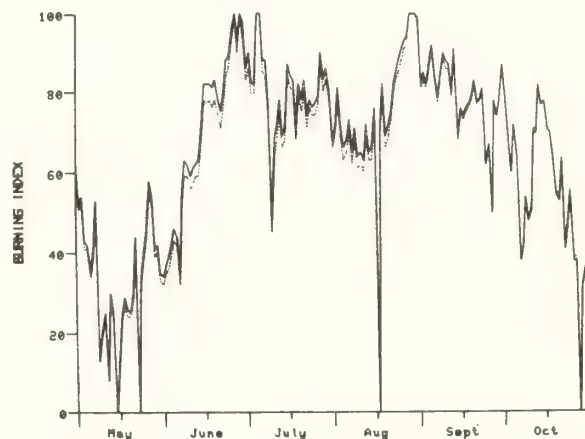


Figure 11.--Burning Index calculated for Lytle Creek (1974 data) with a constant solar radiation intensity and day-length value (dotted lines) and with variable solar radiation intensity and day-length values (solid lines).

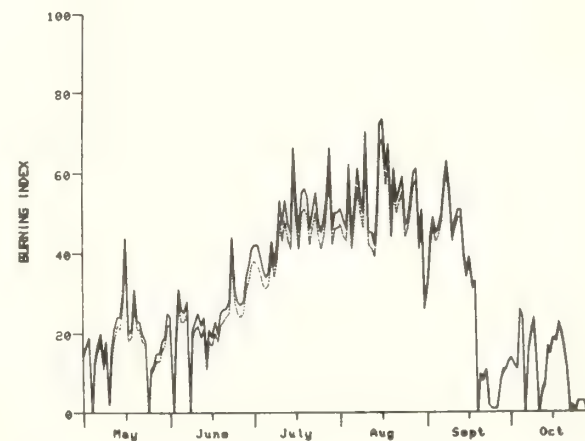


Figure 12.--Burning Index calculated for Libby (1973 data) with a constant solar radiation intensity and day-length value (dotted lines) and with variable solar radiation intensity and day-length values (solid lines).

The rate-of-spread is the unrounded value of the spread component. The reaction intensity (IRE) is an intermediate result developed in

the computation of the Energy Release Component ($ERC = IRE/100$). The residence time is dependent on the surface area/volume ratio, so it may be disregarded in this research.

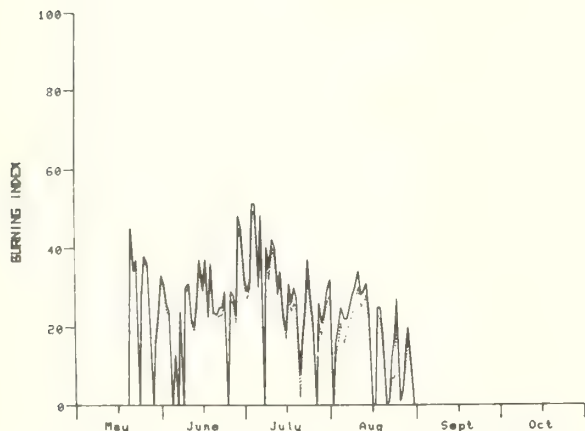


Figure 13.--Burning Index calculated for Fairbanks (1975 data) with a constant solar radiation intensity and day-length value (dotted lines) and with variable solar radiation intensity and day-length values (solid lines).

Thus, the seasonal effects of day length and solar radiation intensity on the Burning Index are expressed primarily through reaction intensity.

There is little seasonal effect in the rate-of-spread term because, for a given windspeed, it is primarily dependent upon the moisture content of fine fuels. The fine fuels, of course, have such a short timelag that even daily cycles have little effect on them.

So, the effect of correcting the Burning Index for seasonal changes of day length and solar radiation intensity is less than for the Energy Release Component, because the

effect of the reaction intensity term in expressing seasonal cycles is diluted by rate-of-spread values in the Burning Index computation.

CONCLUSION

Seasonal changes in day length and solar radiation intensity at various latitudes influence the Man-Caused Ignition Component, the Energy Release Component, and the Burning Index in the 1977 National Fire-Danger Rating System.

Because the Energy Release Component is strongly influenced by large, dead fuels, seasonal effects are greatest in fuel models that have a heavy loading of 100- and 1,000-HRTL fuels. This is primarily because seasonal changes in day length affect the weighting of equilibrium moisture content (EMC) values calculated from early afternoon and early morning temperatures and relative humidities. The weighted EMC largely determines the moisture content of the heavier fuels during the fire season when relative humidity has more effect on these fuels than does precipitation duration.

The Man-Caused Ignition Component and Burning Index are less influenced by seasonal changes in day length and solar radiation intensity because they depend primarily on the moisture content of fine fuels. Because these fuels have such a short timelag (for example, 1 hour), their moisture is determined by the EMC at or near the basic early afternoon observation time. Thus, day length is of minor importance; however, the solar radiation intensity does produce a small effect through its influence on fuel temperature.

Because day length and solar radiation intensity have been shown to be important, appropriate calculations will be included in the computer program for the 1977 National Fire-Danger Rating System.

Development of a Fire Danger Rating System for Universal Application¹

William E. Reifsnyder²/

Abstract.--At the request of the World Meteorological Organization, a hierarchical system for rating forest fire danger was developed. The system uses generally available meteorological measurements to evaluate the flammability of wildland fuels anywhere in the world. The basic framework is that of the US National Fire Danger Rating System. Key elements are adapted from that system and the Australian system.

INTRODUCTION

Fire is a natural part of many of the world's ecosystems. Indeed, many wildland ecosystems depend on fire for their regeneration and maintenance. But fire also, from man's point of view, exerts destructive influences on many ecosystems. Organic matter is consumed, trees are killed, soil is exposed to the erosive power of rainfall.

The delicate nature of the balance between man and the wildland environment is perhaps nowhere more evident than in the relationship between man, fire and the environment. Man often needs to use fire in manipulating the wildland ecosystem, but unwanted wildfire can destroy the values he has worked so hard to protect and develop.

Recognizing this, the United Nations Environment Program (UNEP) has undertaken several programs to further the understanding, use, and control of wildland fire for the protection of man's environment. In particular, UNEP asked WMO to prepare a report on forest fire danger rating systems and forest fire weather forecasting. I was asked by WMO to evaluate existing systems and to prepare, if possible, a system that could be used by developing countries or others recognizing a need for such a system.

RELATIONSHIP OF WEATHER AND CLIMATE TO WILDLAND FIRE BEHAVIOR

Given a complex of fuels in a wildland environment, the way that a fire develops and burns from an ignition source depends largely on meteorological and climate factors. The general structure of vegetation in an area is largely determined by the climate of the area, particularly such factors as temperature, precipitation and radiant energy input. The phenological development of plants in a vegetation complex depends in considerable measure on the seasonal progression of climatic elements.

Extended periods of low precipitation, low humidity, and high temperature produce conditions in which dead vegetation (and even to some extent living material) becomes highly flammable. Thus, in many regions, a well defined "fire season" is established.

The way that a particular fire burns in a complex of wildland fuels depends largely on meteorological conditions at that time, together with such other factors as topography and distribution of ignition sources. As early as 1913, forecasters of the U.S. Weather Bureau were authorized to issue fire weather warnings (Williams, 1916). These were primarily forecasts of impending dry and windy weather.

Development of specific information on the relationship between weather variables and fire behavior received great impetus from the work of Harry T. Gisborne in the United States and J. G. Wright in Canada during the decade of the 1920's (Gisborne, 1925; Wright, 1932). These men pioneered the development of systems for integrating weather variables into single index numbers that could be used to predict

¹/ Paper presented at the Fourth National Conference on Fire and Forest Meteorology, St. Louis, MO, November 16-18, 1976.

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the behavior of fires and the difficulty of controlling them. Their work in the development of forest fire danger ratings and "fire danger meters" formed the basis for much of the subsequent work that went on not only in North America but elsewhere in the world.

DISTRIBUTION OF FIRES AND FIRE WEATHER IN SPACE AND TIME

Fires can burn in wildland fuels anytime that antecedent and present weather have brought a sufficient quantity of fuel to a dry and flammable state. All that is needed is a source of ignition; this can be produced either by lightning or by man. Fires occur in nearly every vegetation type in the world with the possible exception of the tropical rain forest. Even here, however, fire is used in land clearing and shifting agriculture. Only a few forests in the world are so continuously wet that fires are virtually impossible.

The physical laws that control the behavior of wildland fires are the same everywhere on earth. It can be assumed, therefore, that it is feasible to develop a generalized system for predicting the behavior of fires in any vegetative complex subject to burning and to predict the weather variables that influence such behavior.

RELATIONSHIP TO FOREST AND WILDLAND MANAGEMENT

As a prerequisite for the development of a fire danger rating system, it is necessary to establish the uses to which such a system will be put. The level and intensity of wildland management will determine the interest in and need for the rating and predicting of fire danger. These management criteria will determine the nature of the system developed, its complexity and sophistication, the type and size of organization developed to implement the system, and so forth. The following non-exhaustive list of management criteria and activities is illustrative:

- (a) protection of life and property in wildland environments;
- (b) protection of the commercial value of the forest resource;
- (c) protection of watersheds from fire-accelerated erosion;
- (d) protection of high value plantations;
- (e) controlled use of fire for forest regeneration;
- (f) controlled use of fire for fuel reduction; and

- (g) use of fire in land clearing and vegetation-type conversion.

The first step in establishing a fire control plan must therefore be a statement and analysis of the fire-related management objectives. This in turn will imply the nature and level of fire-weather forecasting services required and the kind and complexity of fire danger rating system needed to further the objectives of the fire control plan. In terms of a fire danger rating system, possibilities range from a simple ignition index that will estimate the likelihood that fires can start and burn from natural or man-originated sources; to a multilevel system that will predict fire behavior, difficulty of control, manpower requirements, and so forth.

HIERARCHY OF FIRE DANGER RATING SYSTEMS

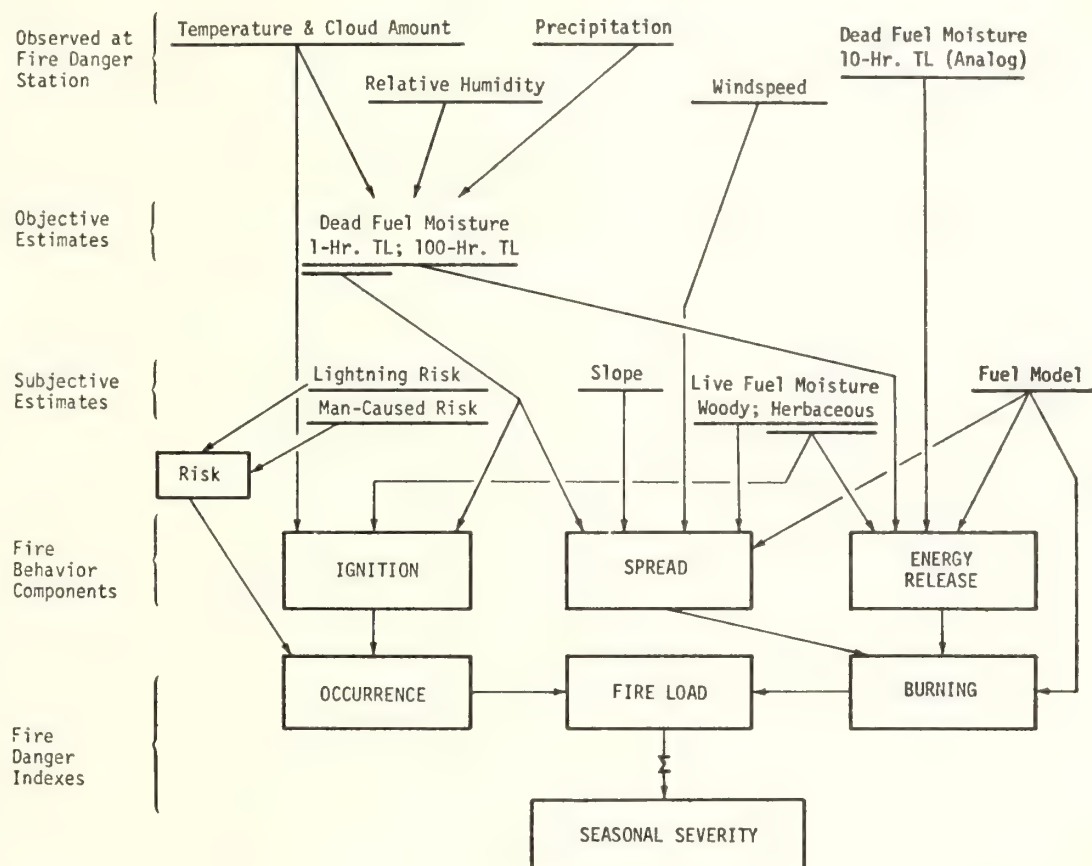
Discussion of the various levels of a fire danger rating system and the management uses to which the various components may be put is facilitated through examination of the structure of the U.S. National Fire Danger Rating System (Deeming and others, 1974). Although this was developed specifically for the U.S. system currently in use, it can be used as the basis for analyzing systems currently used elsewhere and can be used as the basis for the development of a system for universal application (fig. 1).

The meteorological elements that are inputs to this scheme relate either to the moisture content of various sizes of dead fuels¹ or to wind speed.

Level 1: Ignition. An ignition index indicates the ease with which fine fuels can be ignited from a simple ignition source such as a match, cigarette or lightning strike. It can be used by the forest manager as a measure of the likelihood that wildland fires would

¹In this scheme, fuels are ordered according to their time rate of response to moisture changes. A one-hour timelag (TL) fuel is one that achieves 62% (1/e) of its equilibrium moisture content after a step change in ambient humidity. In the natural fuel complex, this represents fine fuels such as dry grass, individual conifer needles or hardwood leaves, small twigs, and the surface of the litter layer. Ten-hour timelag fuels include large twigs, branches with characteristic diameters of 1 to 3 centimeters and the surface litter layer of 2 centimeters depth. 100-hour timelag fuels include branch material from 3 to 8 centimeters in diameter and litter layers from two to 10 centimeters deep.

Figure 1. Structure of the U.S. National Fire Danger Rating System. (Deeming and others, 1974.)



start accidentally from the activities of man in wildland areas. From a meteorological point of view it is dependent primarily upon the moisture content and temperature of the fuel particle.

Level 2: Occurrence. The occurrence index is defined as a number related to the potential fire incidence within a specific area. It is related to the number of potential ignition sources within the area and to the ignition index. It gives the forest manager an indication of the relative number of fires that may occur in the rated area. It can be used, for example, as a guide to the level of detection services required.

Level 3: Spread Index. A spread index predicts the forward rate of spread of a fire in a particular fuel type on a particular slope when subjected to specific meteorological conditions. It can be used as a guide to estimate the time that deliberately set controlled fires

will take to cover the area within a controlled burn. It can be used to estimate the speed with which control lines must be built in order to contain a fire.

Level 4: Energy Release. The energy release index, as its name implies, indicates the combustion rate and heat output in a given fuel type for a given complex of fuel moisture contents. It indicates how close to the fire edge fire control crews can work and thus may be used as a guide to effective attack methods.

Level 5: Burning Index. Burning index is defined as a number related to the contribution that fire behavior makes to the potential amount of effort needed to contain a fire in a particular fuel type within a rating area. It can thus be used to estimate the number of fire control personnel, kind and quantity of suppression equipment and so forth.

Level 6: Fire Load. The fire load index,

combining the burning index and the occurrence index, indicates the potential fire control job that may be faced by a forest manager in an area on a particular day. It provides an indication of the likely total fire suppression effort required on an area to meet the stated forest management objectives.

Level 7: Seasonal Severity. The seasonal severity index is a seasonal summation of fire load indices and is useful as an administrative tool for apportioning suppression forces and services among various units of a wildland area.

Obviously, not every forest fire control organization will need to utilize all of these indices. Developing organizations will start at a low level in the hierarchy and add components as their needs develop. Specific recommendations for such development follow.

GENERAL RECOMMENDATIONS

Development and utilization of a fire-danger rating system and a fire-weather forecasting system are essentially open-ended and can be pursued to any level appropriate to a particular nation's or region's needs, and to the quantity and quality of its cadre of technicians and scientists. For a nation with a small forestry department and perhaps a single weather forecasting center, the level of initial operations must necessarily be low. That is to say, the level of activity in rating and forecasting fire danger should be appropriate not only to the magnitude of the fire problem but also to the size and capabilities of the forestry and meteorological organizations.

CONSTRAINTS

In developing the specific recommendations contained in the next section, a number of assumptions and constraints were observed. The major ones follow.

The system should have universal application. Since fires everywhere burn subject to the same physical laws, it should be possible to develop a system that can be applied anywhere. Although this establishes the possibility of developing a universal system, the desirability rests on other grounds. First of all, the task of developing a separate system for each nation or for separate areas within each nation (as typified by the early development of fire-danger rating systems in the U.S.A.) is wasteful of scientific and technical talent. Development of separate systems would also delay the process in many areas where other tasks may have higher

priority. Development of a single system for rating fire danger and fire climate will permit the intercomparison of fire hazards on a world-wide basis. This will permit rational studies of the allocation of fire research and fire-suppression efforts by national, regional, and United Nations agencies.

The system should be flexible and adaptable to a variety of administrative and governmental structures. The proposed system should not be keyed to the way any particular nation organizes its forestry and meteorological services. If possible, the meteorological parameters specified should be those that are normally produced by a forecast center.

The proposed system should be simple and easy to apply. There is an obvious need for simplicity in formulating and using the fire-danger rating system. Obviously, a system can be as complicated as needed; but at the start it should be easily usable and understandable by field personnel. Otherwise, it simply will not be used.

The system should be hierarchical in nature. As implied earlier, various fire control organizations will need systems of different levels of sophistication. The proposed system should permit an orderly and logical transition from one hierarchical level to another. Each level should represent something added to the level below, rather than something substituted for it and replacing it. Some substitution may of course be necessary as scientific understanding of the meteorological influences on fire behavior increases. But if the underlying hierarchical structure is sound, such substitutions can be made with minimal disruption to the operation of the system.

DEVELOPMENT OF AN IGNITION INDEX

The single most important wildland fire danger index for a nation that is developing a wildland fire management system is an index that will indicate the likelihood that a wildland fire will start given a source of ignition such as a cigarette, debris fire or a lightning strike. Wildland fires normally start in fine dead fuels such as dry grass or leaf litter. The drier the fuels, the more likely an ignition source will start a fire. The moisture content of the fine dead fuels depends on the temperature of the fuel particle and on the relative humidity of the air immediately in contact with it. Fine dead fuels respond very quickly to changes in ambient temperature and humidity conditions. However, if the grass and herbaceous vegetation is only partially cured, the effective moisture content of the fine fuels is raised

because of the high moisture content of the green living material.

One existing rating system, the US National Fire Danger Rating System (NFDRS), includes a component that estimates the moisture content of fine fuels less than 7 millimeters in diameter. (These are the so-called one-hour timelag fuels indicated on figure 1.) Because equilibrium moisture content of a fine fuel depends on whether the fuel particle is undergoing a drying or wetting phase, an assumption must be made as to the regime to which the particle is being subjected. The NFDRS assumes a drying phase inasmuch as high fire danger normally occurs in the afternoon after the fuels have been drying from a morning moist condition (Fosberg and Deeming, 1971). Although a specific drying regime was utilized in the preparation of the tables, that appropriate to a continental climate, it is likely that the system will work reasonably well anywhere, certainly as a first approximation. The meteorological elements required for the estimate of the ignition index are air temperature and relative humidity measured in a standard weather shelter and the state of the weather (whether sunny or cloudy). Thus, calculations can be made based on standard meteorological observations. The time of observation should be close to noon.

DEVELOPMENT OF RATE-OF-SPREAD INDEX

The rate of spread of a fire in a given fuel complex depends on wind speed and slope in addition to fuel moisture content. Also, the moisture content of heavier fuels influences the intensity of a fire as well as its forward spread. These are fundamental fire behavior parameters that are important not only to the control of wild fires but also to the behavior of fires set for management purposes. For these purposes, it is desirable that the danger rating be interpretable directly in terms of forward spread of fire.

The Australian system (McArthur, 1967) fits these criteria. It was developed for eucalypt forests in Australia and has been applied successfully in the subtropical climates in Australia and in eucalypt and pine plantations in Zambia (FAO, 1971). It should be noted that the McArthur system is based on more than one thousand experimental fires, permitting direct interpretation in terms of rate of spread.

The system can be described briefly as follows. The system uses standard meteorological measurements of temperature, relative humidity, dewpoint, wind speed, and rainfall as basic input parameters. Fine-fuel moisture

is determined implicitly through the measurement of temperature and relative humidity. Moisture content of medium and heavy fuels is kept track of through a bookkeeping system utilizing rainfall amount, days since rain, and maximum air temperature. Wind speed is included as a major influence on rate of spread and rate of combustion.

The resultant index number can be interpreted in terms of rate of forward spread and flame height for various quantities of fine dead fuel ranging from five to 25 tonnes per hectare.

It should be noted that the US NFDRS has the capability of evaluating a danger rating for an essentially infinite variety of fuel types in which fuel amounts are distributed among fine, medium and heavy fuels. At present, the system has been adapted to eight different fuel types (called fuel models) representing typical fuels found in the United States. Development of this system should be monitored for possible application in other regions inasmuch as it appears to be highly adaptable to any fuel complex and any climatic regime. In its present form, it may be difficult for a forestry organization unfamiliar with fire danger rating systems to implement it because of its relative complexity.

IMPLEMENTATION

The Food and Agriculture Organization of the United Nations has under advisement the establishment of several regional fire weather forecasting and research centers. These have been proposed for the Mediterranean region, Africa and Central America. When and if these centers are established, the proposed fire danger rating system will be implemented on a trial basis. This should provide a valid test of validity for use in other regions of the world.

ACKNOWLEDGEMENT

The developments reported in this paper were accomplished while the author was employed as a consultant to the World Meteorological Organization. A more complete account, including proposals for fire weather forecasting systems, will be published as a WMO Technical Note.

LITERATURE CITED

Deeming, John E., J. W. Lancaster, M. H. Fosberg, R. W. Furman and M. J. Schroeder.
1974. National fire-danger rating system.

- USDA Forest Service Research Paper RM-84.
53 p.
- Food and Agriculture Organization.
1971. Forest industries feasibility study, Zambia. Fire protection of industrial plantations. Food and Agriculture Organization of the United Nations, FO:SF/ZAM 5. Technical Report 4, 70 p.
- Fosberg, M. A., and J. A. Deeming.
1971. Derivation of the 1- and 10-hour time lag fuel moisture calculations for fire-danger rating. USDA Forest Service Research Note RM-207, 8 p.
- Gisborne, H. T.
1925. Using weather forecasts for predicting forest fire danger. Monthly Weather Rev. 53(2):58-60.
- McArthur, A. G.
1967. Fire behaviour in Eucalypt forests. Australia Forestry and Timber Bureau. Leaflet No. 107, 36 p.
- Williams, H. E.
1916. Fire-weather warnings. Monthly Weather Review 44(3):133-135.
- Wright, J. G.
1932. Forest fire hazard research as developed and conducted at the Petawawa Forest Experiment Station. Canada Dept. of Int. Forest Service. Forest Fire Hazard Paper No. 2. (Reprinted 1967 as FFRI Inform. Report FF-X-5).

Session IV
Atmospheric Aspects of Forest Insect and Disease Control

Chairman: Keith Shea
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Washington, D.C.

Airflow in the Forest Canopy — A Review of Current Research on Modeling the Momentum Balance^{1,2,3}

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Abstract.--There is currently no generally accepted model for the momentum balance of air flow in a forest canopy. The defects in existing models are fundamental. They reflect basically a lack of information on the flow near highly porous, bluff, and irregular bodies at appreciable speeds, as well as conceptual difficulties in superimposing turbulence fields of differing macroscales and random secondary flow patterns.

Three recent models for wind flow in a forest canopy (developed by Cionco et al, Barr, and Bergen) are examined as divergent solutions to the problems of the vertical velocity profile in an extensive forest stand. The models are typical of three main approaches to the problem of estimating the vertical shear stress terms for the time- and space-averaged momentum balance through the canopy layer.

In the first, the vertical momentum transport is attributed entirely to local turbulence, and the eddy viscosity is related to the average local speed and the foliage drag by equating the dissipation of kinetic energy by the foliage drag to the work done by the mean flow via the vertical turbulent shear stress.

In the second solution, an effective viscosity is assumed to depend on local speed and a length scale determined by the total canopy density, the tree height, and the distance to the forest floor. The relation is determined such that it interpolates between very high densities and a vanishing density.

The last model attempts to evaluate the apparent viscosity empirically as a function of foliage distribution and local speed. The vertical shear stress is assumed due to a superposition of (1) turbulent motions due to foliage wakes and those due to large-scale vertical shear, and (2) small scale secondary circulations.

None of these models correctly predicts the velocity and/or speed maximum found in the subcanopy space in field and wind tunnel investigations. The trend in opinion on this important difficulty in all current models is that local circulations occur in a typical forest stand which are of the same vertical scale as the canopy. Transport due to these motions cannot be parameterized in the same fashion for the space and time averages necessary to ensure continuity between the heterogeneous canopy layer and upper homogeneous region as is the case for smaller scales of motion. Therefore, an extra term of a relatively complex nature appears in the momentum balance.

^{1/} Paper presented at the Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, Nov. 16-18, 1976.

^{2/} Research funded in part by the USDA-expanded Douglas-fir Tussock Moth Research and Development Program, P.O. Box 3041, Portland, Oregon.

^{3/} Because of the length of this paper, it will be issued at a later date as a Rocky Mountain Forest and Range Experiment Station publication.

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Atmospheric Transport of Insects and Disease^{1,2}

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Abstract. Airborne insects and diseases cause considerable damage to forest ecosystems. The meteorological factors influencing the production, release, dispersion, deposition and viability of airborne insects and fungus spores are examined. The potential for disease spread is examined over both long and short distances. Modeling as a tool for integrating data, predicting spread and use in control is discussed.

INTRODUCTION

The major concern with damaging forest insects and diseases lies in their ability to spread. If they didn't spread and occupy new space, there would be little need for concern.

Airborne dispersal is the most rapid mechanism for the spread of insects and diseases and most dangerous forest pests are spread in this way. This spread is influenced by meteorological conditions, and it is this influence on the production, release, viability, dispersion and deposition of insects and fungus spores which are examined here. Questions involving how far airborne forest insects and diseases are capable of spreading, the prediction of spread, and the use of systems analysis as a tool for control are also discussed.

THE IMPACT OF AIRBORNE DISEASES AND INSECTS

Our major interest in understanding and controlling forest pests results from the damage they do to timber resources. Economic damage to forests by airborne insects and diseases is considerable and annual growth losses and mortality amount to millions of dollars (Davidson and Prentice 1967).

^{1/} Paper presented at the 4th National Conference on Fire and Forest Meteorology, St. Louis, Nov. 16-18, 1976.

^{2/} Partial support for this work was provided by the USDA Douglas-fir Tussock Moth Program, Portland, Oregon.

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Several examples illustrate this point. The gypsy moth (Porthetria dispar) had defoliated thousands of hectares of hardwoods in the northeastern United States since its introduction in the 1890's. In 1973, defoliation occurred on 728,450 ha (U.S. Forest Service 1975). Similar destructive defoliation is caused by the Douglas-fir tussock moth (Orygia pseudotsugata) in the western United States. Nearly 324,000 ha of Douglas-fir and true firs in Oregon, Washington and Idaho sustained some degree of defoliation (U.S. Forest Service 1975). The spruce budworm (Choristoneura fumiferana), the most widely distributed destructive insect in North America, has killed many trees in the last 150 years and 2.5 million ha were affected in 1973 in the east (U.S. Forest Service 1975).

Airborne forest diseases, which are mostly caused by fungi, are generally not as dramatically evident as insect outbreaks, but they do cause considerable economic damage. The annual loss to white pine blister rust caused by Cronartium ribicola has been estimated at approximately 9.6 million m³ of lumber (Davidson and Prentice 1967). The disease generally makes the growing of nonresistant white pine an unprofitable venture.

Fomes annosus root rot has been a serious problem in Europe for more than 100 years, particularly in thinned plantations where airborne spores infect exposed stumps. This root rot has emerged as a problem in intensively managed conifer stands in the United States and annual mortality in the southeast is estimated to be 192,500 m³ (Davidson and Prentice 1967). Fusiform rust caused by Cronartium fusiforme is a limiting factor in the successful management of loblolly and slash pines in the southern United States.

In the Lakes States region hypoxylon canker (Hypoxylon pruinaum) is estimated to cause an

annual growth loss in aspen of 5.4 million m³, which is equivalent to about 31% of the net growth of aspen types in the survey area.

There are many more examples of the impact of airborne insects and diseases which could be listed, but the above examples serve well to illustrate the loss of fiber which occurs each year due to these agents which otherwise would be available for use.

PROPERTIES OF AIRBORNE FUNGUS SPORES AND INSECTS

Airborne fungus spores and insects differ considerably with respect to size, shape, terminal velocity, viability and metabolic state. Insects generally become airborne in an actively metabolizing state and many insects are not well adapted for aerial dispersal. Fungi are generally dispersed in the form of spores (either sexual or asexual) which are hardier, metabolically less active, and often better adapted to aerial dispersal (Gregory 1973). Hyphae fragments may also be airborne. The above properties, in combination with meteorological conditions, largely determine the distance of spread of airborne insects and diseases.

Properties of Spores

Spores may be unicellular or possess a few cells with an outer cell wall surrounding the nuclear material. The spore walls may be very thick in some species. The surface may be hydrophobic or hydrophilic, sticky, smooth or spiny. Spores may be transparent and colorless (hyaline) or colored, with yellows, reds, browns and purples being the most common. Although most spores are dispersed as a single unit aggregates do occur.

Generally specific gravities of spores fall between 1.1 and 1.2, although lower and higher values do occur. Spore sizes and shapes are variable. Small spores tend to be spherical, whereas larger spores may be extremely elongated. Spore diameters range from less than 5 μ m to as much as 115 x 350 μ m for some ascospores. Most spores are 5 - 50 μ m in diameter.

Spore surfaces may also be electrically charged, either positive or negative. The size, shape, density, surface roughness and electrostatic charge control the aerodynamic behavior of the spore, particularly the terminal velocity.

Fungus spores are subjected to gravity fall at a terminal velocity governed by Stoke's law, which in simplified form states that the rate of fall per second of a spherical spore is proportional to the square of its radius. Table 1 shows the dimensions and terminal velocities of some common spores. Spores of *Fomes annosus*, for example, are well adapted for aerial dispersal, because of their small size, although larger spores such as wheat rust (*Puccinia graminis tritici*) urediospores are capable of traveling long distances. Spore size thus does not entirely determine travel distance. When turbulence is high, say during the day, differences in terminal velocities are minimized. Many larger spores are also elongated and the terminal velocity of such spores is less than that of spherical spores of the same volume.

Viability ultimately determines the effective spread of spores since they must arrive in a living state to cause disease. The airborne phase can be regarded as a retarded decay process, and death of the cells is sometimes

Table 1. Terminal velocities and dimensions of representative spores.

Genus or species	Spore type	Dimensions (μ m)	Terminal velocity cm sec ⁻¹
<i>Alternaria</i> sp.	conidia	20 x 10	0.3
<i>Cladosporium</i> sp.	conidia	10-14 x 3.8-5.2	0.07
<i>Cronartium ribicola</i>	urediospore	22 x 19	0.8
<i>Fomes annosus</i>	basidiospore	4.5 x 3.5-4.5	0.07
<i>Puccinia graminis tritici</i>	urediospore	30 x 18	1.06

rapid (Gregory 1973). Humidity, temperature and radiation are the three factors known to greatly influence viability.

The hazard of dessication is greatest in the daytime and in air layers near the ground. At higher altitudes, and at night, conditions are more favorable. Temperatures in the upper atmosphere may in fact be preservative rather than lethal.

The wavelengths of radiation which are most lethal are in the ultraviolet (UV) region. Ascent to the upper air greatly increases the UV dosage except in clouds. Pigmented spores have more protection than hyaline ones. There is also some evidence of the lethal action of radiation in the visible region (Gregory, 1973). Photoreactivation may reduce apparent radiation damage as spores return to lower altitudes. Interactions of temperature, moisture and radiation are not well understood, but Carlisle (1970) has shown that low temperatures and dessication may protect spores against radiation damage.

The impact of air pollutants on spore viability is also not well understood, but it is thought to vary with atmospheric conditions. Lighthart (1973), for example, found that high humidities protected airborne bacteria from loss of viability due to carbon monoxide exposure. Viability varies greatly among the classes of airborne fungi. Kramer and Pady (1968) found Fungi Imperfecti with dark thick spore walls had the highest average germination (80%), while lighter colored Fungi Imperfecti such as *Cladosporium* sp. had lower rates of germination (45%). Basidiospores were considerably lower at 6%. Rust urediospores had 32% germination. Many common forest pathogens are basidiomycetes with hyaline spores.

Some spores have a very short life span in the atmosphere. *Cronartium ribicola* basidio-spores are given a "half-life" of only 5 hours (Yarwood and Sylvester 1959). Other spores have considerably longer life spans. Pady and Kapica (1953) found some spores alive in Arctic air masses originating far to the south.

Properties of Insects

The size and shape of airborne insects is generally quite different from fungus spores. Insects are measured in terms of millimeters rather than micrometers and tend to be elongated. As mentioned previously one of the factors that determines the distance a particle is dispersed in the atmosphere is the terminal velocity. Table 2 shows terminal velocities for various sizes of Douglas-fir tussock moth larvae with and without silk.

Table 2. Terminal velocity of Douglas-fir tussock larvae as functions of length, weight and silk length.

Larval length (cm)	Silk length (cm)	Larval weight (mg)	Terminal velocity (m sec ⁻¹)
0.3*	90	-	0.252
	60	-	0.328
	30	-	0.467
	20	-	0.544
	10	-	0.651
	0	-	0.812
0.318**	0	0.65	1.906
0.635**	0	1.00	2.103
0.794**	0	1.10	2.790
1.100**	0	7.10	2.900

* First instar. Data provided by R. Mitchell, U.S. Forest Service, Corvallis, OR

** Other Instars.

Terminal velocities for these soft bodied larvae are several orders of magnitude greater than those for the fungus spores listed in Table 1, perhaps indicating that insects are not as well adapted for long distance dispersal as fungus spores. Despite their relatively huge size many first instar larvae have several features which enable them to remain airborne longer than would be anticipated. Douglas-fir tussock moth larvae, for example, are covered with a layer of hairs which increases buoyancy. This is supplemented by the silk which trails behind. Table 2 indicates that the terminal velocity of a larva with 90 cm of silk is approximately one third of that with no silk. The elongated shape of the larvae also reduced the terminal velocity. However, larger larvae in later instars have extremely large settling velocities and are poorly adapted for airborne dispersal. Similar relationships were determined by McManus (1973a) for gypsy moth larvae.

Aphids have somewhat similar aerodynamic properties to the larvae discussed above, but lack trailing silk. If insects are much larger than several millimeters in length, they generally need flying power to disperse.

Viability also determines the ultimate effective spread of airborne insects. Wellington (1945) concluded that temperature was the limiting factor in insect survival. Any flying insect cooled below the threshold temperature for flight folds its wings and falls in a trajectory dependent on terminal velocity and wind components. Soft bodied insects such as aphids are soon killed by 0°C temperatures, but other insects can withstand freezing and thawing. Soft bodied insects are also more prone to dessication.

RELEASE OF SPORES AND INSECTS INTO THE ATMOSPHERE

Spore Release

The primary functions of spores are dispersal and survival of a species. There are two strategies of spore production in the fungi. Some species produce large numbers of small spores that facilitate dispersal, but are not well adapted for survival. Other species produce fewer larger spores better adapted for survival.

Spores are either actively or passively discharged (Ingold 1965). Active dispersal involves either turgid living cells or drying and commonly ascomycetes and basidiomycetes employ these methods. With passive dispersal either slime-spore or dry-spore discharge occurs and this method is employed largely by Fungi Imperfecti. Rain and wind are the most common triggering mechanisms. It might be expected that many of the fungal propagules in the air would be associated with dust particles. However, this does not appear to be so and most spores appear to be directly liberated into the atmosphere.

Spore release commonly follows circadian patterns determined by one of the major environmental factors which also show rhythms of this kind, e.g., light, temperature, relative humidity and wind velocity. For some spores the maximum release is at night or in the early morning before dawn, or shortly after sunrise (ascomycetes and basidiomycetes). Other spores have a maximum early in the afternoon, particularly colored thick walled spores exhibiting passive release (Fungi Imperfecti). Normally one of these seems to dominate. In a number of ascomycetes light induction or inhibition is dominant with light affecting the last stages of maturation.

Early afternoon and predawn maxima in spore release is generally related to temperature and relative humidity. Wood (1966) found a maximum release of basidiospores of Fomes annosus around midnight and a minimum around

noon. Basidiospores of Cronartium fusiforme show a similar pattern with spores being produced at night and early morning. Occurrence is closely related to the number of hours exceeding 97% relative humidity (Snow and Froelich 1968). Cronartium ribicola is also similar.

How many spores are produced by a single fruiting body? Ganoderma applanatum, a common wood rotting organism may produce 3×10^{10} spores in a single day and a 2.5 cm diameter colony of Penicillium may produce as many as 4×10^8 conidia day⁻¹ (Ingold 1946). Environmental conditions, particularly moisture and temperature influence the length of time a fruiting body sustains production. In the polypore fungi many species are woody and perennial and are able to continue sporulating throughout the year as long as moisture and temperature conditions are suitable.

With Fomes annosus (a polypore fungus) some spores are produced in most seasons of the year except during periods of extreme drought or cold in Europe, Canada and the northern United States. Maximum production occurs in late summer or fall. In the southeastern United States, greatest spore production occurs during fall, winter and spring. Few, if any, are produced in summer (Hodges 1969).

To become airborne spores must pass through the laminar boundary layer surrounding the fruiting body. During calm periods at night this layer is very thick, but it may be reduced to <1mm with high winds. Once free of this boundary layer, spores are dispersed in the wind field.

Insect Release

There are two major insect forms dispersed in the atmosphere; (1) non-winged forms including immature insects, such as Lepidopterous larvae, and wingless adults, such as aphids and (2) winged forms.

The non-winged forms are more analogous to fungus spores since they are under many of the same environmental influences, particularly the effect of gravity. Small winged forms, although having the ability to fly, sometimes maintain positions where they do not use their flying power and are passively dispersed. Leaf hoppers behave in this manner.

The actual movement of the insect into the air is usually directly influenced by microclimate. Temperature probably has the greatest influence on the activity of arthropods. Wellington (1945) found that the minimum temperature (threshold) for flight initiation in three species of Homoptera was about 14°C, with the bean aphid having a threshold temperature of

13-15°C.

With winged insects temperature may limit activity for short periods but it generally does not prevent dispersion. However, with passively blown forms temperature may limit predispersal behavior and greatly inhibit dispersal. Gypsy moth larvae, for example, after hatching in spring, climb to dispersal sites in the tree tops in response to light. McManus (personal communication), however, indicated that dispersal did not occur when a cyclonic disturbance dominated for three days resulting in temperatures below the threshold of activity for the larvae. Similar behavior is exhibited by tussock moth larvae. Larvae observed by the author did not climb unless temperatures were above a threshold of 11-13°C. In general, humidity is not thought to be a limiting factor in dispersion. Activity is greatest at lower relative humidities.

High velocity winds are inhibiting to insect release; very slight breezes appear to stimulate both the flight behavior of winged forms and the dispersive behavior of passively carried insects. McManus (1973a) found that gypsy moth larvae will actively drop when winds are less than 8 km hr⁻¹, but adhere when winds are higher. Jensen and Wallin (1965) indicate that aphid take off was delayed by 4-10 hours by winds of 4-8 km hr⁻¹ and delayed 24 hours by winds of 8 km hr⁻¹. This phenomena is common in the Orders Diptera, Thysanoptera, Hemiptera and Homoptera.

Most insects tend to take off when winds are suitable for dispersal, which generally for passively dispersed insects, tends to be at a maximum in the early afternoon. Many adult insects including the spruce budworm, however, are released at night.

Although crowding has been frequently mentioned as a stimulus to dispersal, there is a large body of evidence to the contrary (McManus, personal communication). The locust phase of many grasshoppers, however, is induced by increased densities in their permanent breeding ground. Generally, it can be concluded that many adult insects are released at night while most larval and immature insects are released during the day. On a seasonal basis most activity is in spring, summer and fall.

DISPERSAL AND DEPOSITION PROCESSES, AND ATMOSPHERIC CONCENTRATIONS OF SPORES AND INSECTS

Dispersal Processes

The processes determining release into the

atmosphere of fungus spores and insects have been described. What is the fate of these particles once they are released into the atmosphere? They are dispersed downwind vertically and horizontally as a result of atmosphere turbulence. Turbulence can be either mechanical or thermal in origin. Atmosphere stability also markedly affects dispersion with greatest dispersion under unstable conditions and least under stable conditions. Three scales of atmospheric transport are recognized; micro-scale, meso-scale and large-scale. Each possesses definite time and space scales.

Micro-scale transport is limited to small time scales (< 1 hour) and space scales varying from centimeters to a few hundred metres (short distance dispersal). For meso-scale transport, the appropriate time and space scales are days and a few hundred kilometers or less. Large-scale transport encompasses global circulation patterns and very long time scales. The last two classes are considered long distance dispersal.

Deposition Processes

The principal methods of spore and insect deposition in nature are sedimentation, impaction, turbulent deposition, rain washing and electrostatic deposition.

Sedimentation. In turbulent air above ground, the effects of gravity on spore deposition are slight except perhaps under stable conditions on clear nights when the laminar boundary layer may extend several meters. Wind tunnel experiments confirm that the effect of sedimentation is slight at wind speeds exceeding 2 m sec⁻¹ (Gregory 1973). Wind speeds beneath a forest canopy are generally less than 1 m sec⁻¹ and in such cases sedimentation may be important. Sedimentation is more important for insects because of their larger size.

Impaction. Impaction is inefficient when small spores approach large obstructions at low speeds. Conversely, impaction is more efficient when large spores are blown towards small objects at high wind speeds. Large spores would thus seem to have an advantage with respect to impaction on foliage. Dry-spored airborne leaf pathogens usually have large spores while soil inhabitants are characterized by small spores unsuitable for impaction.

The larger size of insects would also favor impaction on foliage. Many forest defoliators such as the Douglas-fir tussock moth also trail silk which aids in the impaction process.

Turbulent Deposition. Spores in air flowing over horizontal surfaces will be deposited

at rates greater than those calculated for sedimentation alone. Rishbeth (1959), for example, found that spores of *Fomes annosus* were even deposited on the undersurface of pine discs exposed a few meters above the ground. These patterns result from turbulent deposition. Turbulent deposition also occurs at larger scales as a result of terrain irregularities and frontal activity.

Rain Washing. The optimum size for deposition in rain varies with the size of prevalent raindrops. Rain washing of air rapidly ends the dispersion process, and it is more effective for larger spores. Snow is unimportant, but large numbers of microorganisms have been found in hail stones. The small spores of *Fomes annosus* are generally not removed from the atmosphere by rain except where frontal activity occurs.

Rain itself is probably not efficient in removing insects from the atmosphere, but insects are commonly brought to the ground in down drafts associated with frontal activity associated with rain.

Electrostatic Deposition. The charges observed on basidiospores and ascospores are presumably acquired in the liberation process. This charge in very small particles such as bacteria could affect the terminal velocity, but in larger fungus spores the effect is less and the initial charge could well be masked by the capture of ions in the atmosphere. Electrostatic deposition is unlikely to be of importance with insects.

The Relative Importance of Deposition Mechanisms. The relative importance of the various deposition processes differs in different positions. Close to the source impaction may dominate except in calm air where sedimentation plays a major role. Rain washing will have a greater effect at longer distances from the source.

Local irregularities in terrain and tree canopies cause turbulence resulting in updrafts and sowndrafts. This may alter the deposition patterns in an area. Turbulent deposition may occur on the lee side of hills and this may explain why gypsy moth and tussock moth infestations are commonly observed on hill tops rather than in valleys.

Levels of Fungi and Insects Found in the Atmosphere

The Background Air Spora Near the Ground

Gregory and Hirst (1957) in a mixed agricultural environment determined that the mean spore concentration at 2 m from June to October

1952, was $12,500 \text{ m}^{-3}$. The commonest spore type was *Cladosporium* sp. (accounting for 47%). Basidiospores are not efficiently caught by surface traps and they may be more important than indicated.

It has already been demonstrated that spores and insects are released into the atmosphere in certain rhythms. This rhythmic variation in spore liberation clearly contributes to airborne concentration. However, if the numbers liberated per hour remained constant, concentration would still tend to be greatest at night because of slower wind speeds, decreased turbulence, absence of convection and temperature inversions. Most spores also show a seasonal periodicity with highest numbers in late spring, summer and fall.

Measurement of the upper air spora was first attempted from towers and tall buildings and later from balloons and aircraft. One would expect a decreasing population with height but this rarely seems to be the case and commonly profiles may increase or be similar up to 1500 m. This is perhaps due to the fact that the thickness of the turbulent zone fluctuates and the vertical concentrations are continually building up or decaying. There is some evidence of a "biological zone" occurring at middle heights, which can probably be explained in terms of temperature inversions, air masses and precipitation (Gregory 1973).

Levels of Insects in the Atmosphere

Although studies of airborne insects have been conducted in recent years, no study as extensive as that recorded by Glick (1942) has been repeated. During 5 years from 1926 to 1931, The USDA in Louisiana sampled 28,739 specimens taken from 6 m above the ground to as high as 5,000 m. The concentrations of total insects at 305 m varied from $3.6 \times 10^{-6} \text{ m}^{-3}$ at night to $3.0 \times 10^{-6} \text{ m}^{-3}$ during the day. Concentration at 6 m was $1.4 \times 10^{-5} \text{ m}^{-3}$. There are wide differences in concentration of insect groups during the day and night. For example, Hymenoptera are far more numerous in the daytime than at night.

Of all insects taken, Diptera were the most abundant and the number decreased with height. At times, however, there may be wide deviations from the expected average population gradient in the upper air. Insects often emerge in great numbers. Butterflies and grasshoppers, flying on their migration or invasion routes will at times fill the air. The author has sampled Douglas-fir tussock moth larvae at a concentration of 0.09 m^{-3} close to the source. These concentrations, however, are still much smaller than even average spore concentrations

Short Distance Dispersal and Deposition in the Forest

Most experiments to determine the distance that fungus spores travel have been conducted over relatively flat terrain (Gregory 1973). Very few studies involving fungus spore or insect dispersal have been conducted in forests. Dispersion beneath the forest canopy may markedly differ from what one expects above the canopy under the same ambient conditions. Below canopy dispersion is particularly important in the case of fungal spore dispersion since many of the spores are released at or near the forest floor.

Van Arsdel (1967) in a paper on the nocturnal diffusion and transport of spores indicated that spores released at night play an important role in the spread of some major forest diseases. Fomes annosus, Cronartium ribicola and Cronartium fusiforme all release hyaline basidiospores at night. Understanding dispersion patterns in and above the forest at night and the expected distance of travel is thus important in understanding the spread of disease.

Edmonds and Driver (1974) and Fritschen and Edmonds (1976) examined dispersion of spores of Fomes annosus and similarly behaving fluorescent particles under a variety of meteorological conditions in a Douglas-fir forest. Basidiospores released near the ground at night under cold air drainage conditions with wind speeds of $< 0.5 \text{ m sec}^{-1}$ are capable of traveling at least 240 m before settling out, but dispersion patterns are complicated by shifting wind fields and traditional statistical dispersion theories do not apply. Deposition patterns are even more complicated and are not necessarily related to spore concentrations above the point of deposition.

Van Arsdel using smoke as a tracer indicates that basidiospores of Cronartium ribicola traveling from Ribes bushes on the forest floor to pine needles at night, may be deposited on pines 27 km from their source. This is a result of below canopy dispersal, updrafts over bodies of water and return flows at a higher level. In any event, hyaline basidiospores are unlikely to travel long distances in a viable state since they are most likely killed by UV radiation during the daytime hours.

Most insects are not expected to travel far in the atmosphere because of their large size and settling velocity. Many lepidopterous larvae probably do not travel more than a few kilometers before deposition. Table 3 shows predicted concentrations of tussock moth larvae as a function of distance from the source using

a traditional atmospheric dispersion model during typical morning and afternoon conditions. This is not to say that some larvae do not travel further. For example, Collins (1915) found gypsy moth larvae 36 km from the nearest source. Certain meteorological conditions associated with frontal activities also promote travel over longer distances.

Long Distance Dispersal and Deposition

There is still some controversy surrounding the ability of plant pathogens and insects to travel long distances, remain viable, and be deposited in numbers enough to cause impacts. Earlier ideas (Butler 1917) held that long distance transport did not need to be taken seriously into account, but there is evidence that some major pathogens do move long distances. To prove aerial dissemination usually requires interception of migrant spores or incontrovertible association between the source and new colonies. The latter situation has been applied to the spread of agricultural pathogens, e.g. with tobacco blue mold in Europe, maize rust in Africa and banana leaf spot in the Caribbean (Hirst and Hurst 1967). More recently coffee rust travel from Africa to Brazil has been added to the list (Bowden et al. 1971). The best known and documented example of long distance transport of spores themselves is the dispersal of wheat rust urediospores from

Table 3. Predicted downwind concentration of tussock moth larvae (percent of concentration at 10 m from source) in typical morning and afternoon conditions.

Distance from source m	Percent of concentration at 10 m	
	Morning*	Afternoon**
10	100	100
100	5.2	6.4
1000	0.24	0.27
10000	0.006	0.003

* Wind speed = 0.5 m sec^{-1} ; stability class C; terminal velocity = $0.252 \text{ cm sec}^{-1}$.

** Wind speed = 3.0 m sec^{-1} ; stability class B; terminal velocity = $0.252 \text{ cm sec}^{-1}$.

Mexico to Canada (Stakman and Harrar 1957) although this is rarely accomplished in one step. Most other examples of international dispersal of diseases are man related, including transmission in ships or aircraft (Zadoks 1967).

It is unlikely that many forest pathogens are transported very long distances in the atmosphere, at least in a viable state, since many of them possess hyaline basidiospores. Viable spores of Fomes annosus, however, have been found 360 km from land (Rishbeth 1959). Aeciospores of Cronartium ribicola may also travel long distances and Christensen (1942) indicated that such spores could be carried 480 to 640 km by wind in the Pacific coast region. Further evidence of long distance transport of these spores is supplied by Pennington (1925) who found Ribes infected with Cronartium ribicola 176 km beyond the limits of white pine and infection centers 240 km to 320 km apart.

Is trans-oceanic transport of pathogens possible? Certainly spores have been detected over oceans, but surface concentrations fall off markedly with distance from land. Kramer et al. (1973) found that surface level spore concentrations were less than 3 m^{-3} in air masses of continental origin 300 to 1300 km west of North America. Principal forms of biota included rust and smut spores Alternaria, Cladosporium, ascospores, and hyphae fragments. Basidiospores were not frequently found.

Similar types of biota were found at higher altitudes by Kramer and Helzapfel (1973). At 3,000 m the population over the continental land masses and the Pacific Ocean differed little. Concentrations averaged from 51 to 1.7 m^{-3} on 13 flights which are higher than those at surface levels. Few basidiospores were found at high altitudes. Pady and Kapica (1955) also did not detect any decreases in biota with distance from land on flights from Montreal to London.

In certain cases, especially cases associated with strong thermal activity and fronts, insects may be capable of traveling long distances. Many dispersal studies have been done on continental coastlines. Moths have been known to cross the Atlantic from the United States to Wales (Miles 1955). Diptera appear to dominate in insect samples taken in Alaska, with mites and springtails next (Gressitt and Yoshimoto 1974). These represent the smallest insect groups. In the Barrow area in Alaska the highest concentration of insects was $1.9 \times 10^{-4} \text{ m}^{-3}$.

Few insects are thus expected to travel long distances over oceans, but many may be

capable of traveling several hundred kilometers. The forest insect most likely to travel these distances is the spruce budworm particularly in association with frontal disturbances.

THE SYSTEMS APPROACH TO DISPERSAL OF INSECTS AND DISEASES

The systems approach and mathematical modeling can be used to integrate the various parts of the dispersal system previously discussed, i.e. production, release, dispersion, deposition and impact. Such an approach serves as a tool for pointing out blanks in our knowledge of systems and thus can guide research. In addition, models may be used to predict dispersal and provide information which can be used for control of forest pests.

Disease Simulators

The importance of the plant - pathogen - environment triangle has been recognized for years, but not until the development of simulation models did it become possible to numerically analyze this system in toto, adding in addition the dimension of time. Application of this concept to plant pathology originated with Waggoner (1968) who constructed a simulator for potato late blight. Several other specific crop pathogen simulators were developed in the intervening years. In addition, a general purpose simulator adaptable to a number of plant diseases has been developed by Shrum (1975).

Few simulation models, however, have been developed for forest diseases and insects. Edmonds (1973) constructed a simulator for Fomes annosus, but points out that one of the most difficult problems is the actual prediction of spore dispersion and deposition in forests. This is in part due to the use of traditional atmospheric dispersion models as sub-models in the overall simulation models.

Traditional atmospheric dispersion models work best over level terrain in neutral stability conditions with moderate to high wind speeds. Such conditions rarely apply in forests which are generally in non-level terrain, and air flows beneath the canopy are extremely complicated. Spore dispersion in Douglas-fir forests is affected by vegetation density with plumes being moved around areas of high density (Edmonds and Driver 1974).

Kinerson and Fritschen (1973) took a different approach to modeling air flow through a forest canopy. They used a direct electrical analog computer. Satisfactory results were obtained with this model. On a larger scale Fosberg et al. (1976) have developed a simple one-

layer model of boundary layer flow for use in mountain valley situations. This model was largely developed for evaluating pollution transport patterns and has been relatively successful.

From this initial analysis of the success of the prediction of spore dispersal one would conclude that success has been somewhat limited. What information, however, is needed for control purposes. Take the situation with Fomes annosus, for example. A forest manager wishes to know if stumps will be infected in a thinning operation. Knowing where the nearest source of spores are located, some approximation can be made with current models as to the distance spores can be expected to effectively spread. Various runs with the model using a variety of meteorological conditions will tell a manager whether the risk of infection is high or low, whether thinning should be delayed to a more favorable season or whether stump treatment is necessary. Predictions, of course, are best close to the source, but become vaguer further from the source, especially in hilly terrain. Similar models can be developed for other forest pathogens.

Insect Simulators

There are fewer examples of the use of systems approach with insect pests. McManus (1973b) developed a conceptual model for the dispersal of gypsy moth larvae. The major difference between the dispersal of gypsy moth larvae and spores of Fomes annosus is the fact that the larvae are generally dispersed above the canopy and spores are dispersed beneath the canopy. The larvae also tend to be released during the afternoon when wind speeds are higher. This situation dictates that prediction of larvae dispersal may be somewhat more successful. There are several complications, however, in that both mechanical and thermal turbulence above the canopy is far different from that over the level terrain. Openings in the forest, for example, create thermal chimneys which may carry insects suddenly aloft. Thus it is expected that prediction of dispersal would be poor on days with strong insolation.

Mason and Edmonds (1974) used an atmospheric dispersion model to predict how far larvae would disperse under various stability conditions. The model predicts that these relatively large particles would travel in large numbers only short distances (< 3 km) although occasional larvae may travel further. A similar situation was encountered by the author in a study of the dispersion of Douglas-fir tussock moth larvae as indicated in Table 3.

Such predictions have implications with

respect to control of these defoliators. Knowing wind speeds and directions, stability conditions and the number of eggs in an area, a simulator could be used to predict where most of the larvae will be expected to be deposited. Control methods including chemical sprays or viruses could then be concentrated in these areas.

Prediction of the spread of flying insects such as the spruce budworm may be somewhat more complicated. These insects are released at night and may travel long distances in the upper air. Trajectory analysis has been used for the spread of several insect spores (Hirst and Hurst 1967) and could be used to predict the spread of the spruce budworm.

CONCLUSIONS

Airborne insects and diseases including the gypsy moth, the Douglas-fir tussock moth, the spruce budworm, Annosus root rot, white pine blister rust and southern fusiform rust cause considerable damage to forest ecosystems. These insects and diseases are similar in their behavior in that propagules are produced, released into the atmosphere, dispersed, and deposited on new sites. Their effective spread, however, depends on their arrival in a viable state.

These insect and disease problems cannot be eradicated, but an understanding of how meteorological and biological factors influence the above pathway enables one to pinpoint spots where control measures can be ecologically and economically best used.

Use of mathematical modeling quantifies this approach and can be used to predict spread. This prediction, however, is sometimes difficult in the forest environment, particularly in complicated terrain. Our inability to accurately predict airborne dispersal still remains the weak link in the modeling approach. Certain techniques, including the use of analog models provide hope for the future.

LITERATURE CITED

- Bowden, J., P. H. Gregory, and C. G. Johnson.
1971. Possible wind transport of coffee leaf rust across the Atlantic Ocean. *Nature*, Lond. 229:500-501.
- Butler, E. J.
1917. The dissemination of parasitic fungi and international legislation. *Mem. Dept. Agric. India*, Bot. 9:1-73.
- Carlisle, M. J.
1970. The photoresponses of fungi, p. 309-344. In P. Halldal (ed.). *The photobiology*

- of microorganisms. Wiley, N.Y.
- Christensen, J. J.
1942. Long distance dispersal of plant pathogens, p. 78-87. In F. R. Moulton (ed.). *Aerobiology*. Publ. No. 17. AAAS, Washington, D.C. 289 p.
- Collins, C. W.
1915. Dispersion of gypsy moth larvae by the wind. USDA Bull. 273. 23 p.
- Davidson, A. G., and R. M. Prentice (eds.).
1967. Important forest insects and diseases of mutual concern to Canada, the United States, and Mexico. Working groups on forest insects and diseases. N. Amer. For. Comm. FAO. Dept. For. Rural Devel. Canada. 248 p.
- Edmonds, R. L.
1973. Prediction of spread of *Fomes annosus* in forests, p. 77-92. In R. L. Edmonds and W. S. Benninghoff (eds.). *Ecological systems approaches to aerobiology II. Development, demonstration, and evaluation of models*. US/IBP Aerobiology Program Handbook No. 3, AP-USIBP-H-73-3, NTIS Springfield, Va. 186 p.
- Edmonds, R. L. and C. H. Driver.
1974. Dispersion and deposition of spores of *Fomes annosus* and fluorescent particles. *Phytopathology* 64:1313-1321.
- Fosberg, M. A., W. E. Marlatt, and L. Krupnak.
1976. Estimating airflow patterns over complex terrain. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Co. Research Paper RM-162. 16 p.
- Fritschen, L. J., and R. L. Edmonds.
1976. Dispersion of fluorescent particles into and within a Douglas-fir forest. p. 280-301. In R. J. Engelmann and G. A. Schmel (eds.). *Atmosphere surface exchange of particulate and gaseous pollutants (1974)*. ERDA Tech. Info. Center, Oak Ridge
- Gregory, P. H.
1973. *The microbiology of the atmosphere*. Halsted Press, John Wiley and Sons, N.Y.
- Gregory, P. H., and J. M. Hirst.
1957. The summer air spora at Rothamsted in 1952. *J. Gen. Microbiol.* 17:135-152.
- Gresitt, J. L., and C. M. Yoshimoto.
1974. Insect dispersal in northern Alaska. *Pacific Insects* 16:11-30.
- Glick, P. A.
1942. Insect population and migration in the air, p. 88-98. In F. R. Moulton (ed.). *Aerobiology*. Publ. No. 17 AAAS, Washington, D.C. 289 p.
- Hirst, J. M., and G. W. Hurst.
1967. Long-distance spore transport, p. 307-344. In P. H. Gregory and J. L. Monteith (eds.). *Airborne Microbes*. Cambridge University Press. 385 p.
- Hodges, C. S.
1969. Modes of infection and spread of *Fomes annosus*. *Ann. Rev. Phytopath.* 7:247-266.
- Ingold, C. T.
1946. Spore discharge in *Daldinia concentrica*. *Trans. Br. Mycol. Soc.* 29:43-51.
- Ingold, C. T.
1965. *Spore liberation*. Clarendon Press, Oxford 210 p.
- Jensen, R. A., and J. R. Wallin.
1965. Weather and aphids: A review. U.S. Dept. Comm. Tech. Note 5 - Agmet. 1:1-19.
- Kinerson, R. S., Jr., and L. J. Fritschen.
1973. Modeling air flow through vegetation. *Agric. Meteorol.* 12:95-104.
- Kramer, C. L., and E. P. Holzapfel.
1973. Air biota of the upper atmosphere over the Pacific Ocean and Continental United States. *Agric. Meteorol.* 12:83-93.
- Kramer, C. L., J. Wartell, and E. P. Holzapfel.
1973. Surface level trapping of air biota on the Pacific Ocean. *Agric. Meteorol.* 12:49-64.
- Lighthart, B.
1973. Survival of airborne bacteria in a high urban concentration of carbon monoxide. *Appl. Microbiol.* 25:86-91.
- Mason, C. J., and R. L. Edmonds.
1974. An atmospheric dispersion model for gypsy moth larvae, p. 251-252. In S. R. Hanna (ed.). *Symposium on atmospheric diffusion and air pollution*. Am. Meteorol. Soc. Boston, Mass. 434 p.
- Mc Manus, M. L.
1973a. The role of behavior in the dispersal of newly-hatched gypsy moth larvae. USDA For. Ser. Paper NE-267. 10 p.
- Mc Manus, M. L.
1973b. A dispersal model for larvae of the gypsy moth, *Porthetria dispar* L., p. 129-138. In R. L. Edmonds and W. S. Benninghoff (eds.) *Ecological systems approaches to aerobiology II. Development, demonstration and evaluation of models*. US/IBP Aerobiology Program, Handbook No. 3. US-IBP-H-73-3. NTIS, Springfield, Va.
- Miles, P. M.
1955. *Phytometra biloba* Stephens (Lep. Plusiidae) in Wales. *Entomologist's Mon. Mag.* 91:89.
- Pady, S. M., and L. Kapica.
1953. Airborne fungi in the Arctic and other parts of Canada. *Can. J. Bot.* 31:309-323.
- Pady, S. M., and L. Kapica.
1955. Fungi in the air over the Atlantic Ocean. *Mycologia* 47:34-50.
- Pennington, L. H.
1925. Relation of weather conditions to the spread of white pine blister rust in the Pacific Northwest. *J. Agr. Res.* 593-607.
- Rishbeth, J.
1959. Dispersal of *Fomes annosus* Fr. and *Peniophora gigantea* (Fr. Massee). *Trans. Brit. Mycol. Soc.* 42:243-260.
- Shrum, R.
1975. Simulation of wheat stripe rust (*Puccinia striiformis* West) using EPIDEMIC. A flexible plant disease simulator. *Progress*

- Report 347, Coll. Agric. Penn. State Univ., University Park, Pa. 32 p.
- Snow, G. A., and R. C. Froelich.
1968. Daily and seasonal dispersal of basidiospores of *Cronartium fusiforme*. *Phytopathology* 58:1532-1536.
- Stakman, E. C., and J. G. Harrar.
1957. Principles of plant pathology. The Ronald Press Co., N.Y. 581 p.
- U. S. Forest Service.
1975. Forest insect and disease in the United States 1973. Div. Pest Control, For. Serv. USDA, Washington, D.C.
- Van Arsdel, E. P.
1967. The nocturnal diffusion and transport of spores. *Phytopathology* 57:1221-1229.
- Waggoner, P. L.
1968. Weather and the rise and fall of fungi. In W. P. Lowry (ed.). *Biometeorology*. Oregon State Univ. Press, Corvallis, Or.
- Wellington, W. G.
1945. Conditions governing the distribution of insects in the free atmosphere. I. Atmospheric pressure, temperature and humidity. *Can. Entomol.* 77:7-15.
- Wood, F. A.
1966. Pattern of basidiospore release by *Fomes annosus*. *Phytopathology* 56:906-907.
- Yarwood, C. E., and E. S. Sylvester.
1959. The half-life concept of longevity of plant pathogens. *Plant Dis. Repr.* 42:125-128.
- Zadoks, J. C.
1967. International dispersal of fungi. *Neth. J. Pl. Path.* 73. Supp. 1:61-80.

Weather Influences on Insect Populations¹

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Weather influences forest insect populations in many ways, some more obvious than others. The indirect effect of weather operating through the host plant may be more critical to the survival of individuals than the direct effect of specific components of weather. Examples are presented that demonstrate how weather affects forest insect populations and various approaches are discussed.

The relationship between weather and the population dynamics of insects has long been recognized - it makes good sense to suspect that insects that oftentimes feed exposed on plant parts, and that cannot regulate their own body temperatures, should be greatly influenced by components of weather. Although there are literally hundreds of publications in entomology that state that weather is an important factor in the dynamics of many species, there are still relatively few that define the mechanism of how weather is affecting each species.

Weather affects insects as individuals, that is, independently of the population density and is thus said to act as a density independent or catastrophic mortality factor. In the 1950s there was quite a dialogue in the literature on the question "can weather control populations?" According to Varley and Gradwell (1974), if a population is acted upon both by a density dependent factor (such as parasites) and a density independent factor such as weather, then the weather determines the changes, but the density dependent mortality factors are primarily responsible for regulating the population about its average level of abundance.

Weather can produce physiological effects on insect populations in four major ways: (1) by modifying the activity of the endocrine system; Many insects of the temperate zone

respond to decreasing day length by exhibiting a change in the neurosecretory cells of the brain which induces diapause. Diapause is an arrested state of development where the insects reaction to temperature is switched off. This is a tremendous survival mechanism for overwintering in many species; (2) by directly affecting survival; Frost or low winter temperatures may kill large numbers of many species. Wet weather may induce epizootics of fungi or viruses in insect populations, especially in the spring of the year, or it may have an adverse effect on many species of parasites; (3) by affecting rate of development; Emergence of individuals in the spring and the occurrence of developmental stages in the life history during the summer months can usually be predicted by computing day-degrees over a developmental zero or threshold temperature. Most ecologists are aware of Hopkins' Bioclimatic Law (Hopkins 1919) which fits the timing of phenological events in the USA to latitude, longitude, and altitude. Although this is a relative measure, it has had general applicability in agriculture; (4) it has also been demonstrated that temperature and humidity affect the reproductive rate of some species.

In addition to the effects on the physiology of the population, weather also affects the behavior and activity of insects - this is extremely important to our understanding of processes such as dispersal, which I will discuss later.

This is an extremely broad and complex topic to cover in a limited time frame. I have chosen only to discuss some of the more classical studies that have been conducted on

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forest insects wherein a true weather effect has been demonstrated. At the same time, I will present some of the approaches that have been used in the past and discuss the applicability of their findings.

A long term program to investigate the effects of weather on forest insects was first organized by the Department of Forestry of Canada in 1945. It began with a series of biometeorological studies of the spruce budworm in Canadian forests. The program was expanded and is still viable today.

The Canadians rejected the classical approach to biometeorological studies which concentrated on insect development or mortality, or on an isolated biological event such as emergence. Their approach emphasized the effects of weather on the behavior and activity of insects. Meteorological methods were derived mainly from synoptic meteorology, and climatology. This included descriptions of events in the microenvironment in terms of air mass weather and techniques for determining annual or seasonal changes in the numbers and types of weather systems that passed over large forested areas. Simultaneous laboratory and field studies of insects in extreme situations were also conducted (Wellington et al. 1966).

In the past 30 years, over 100 scientific publications have been produced that are mainly biometeorological - most are concerned with the spruce budworm though many intensive studies were also conducted on the white pine weevil, European pine shoot moth, European pine sawfly, lodgepole needle miner and the forest tent caterpillar, to mention only a few. The Canadians eventually realized that their approach was also too narrow - consequently they have recently emphasized other aspects of insect ecology and physiology that are not usually associated with weather, for example, insect biochemistry and nutrition.

If there is a single leader in the area of bioclimatology, it would have to be Dr. W. G. Wellington, who is now located at the University of British Columbia, Vancouver, B.C. In a classic paper entitled "Atmospheric Circulation Processes and Insect Ecology," (Wellington 1954) he stated that there was an increasing interest in the preventive aspects of applied entomology, but that any preventive program must contain and be preceded by methods for forecasting insect population changes.

Wellington complained that biologists are too preoccupied with so-called density dependent biotic factors (parasites, predators and disease) that affect insect populations, and totally disregard the indirect effects of meteorological factors on the equilibrium of a

population by their action on its habitat, its parasites and predators, and on the supply and quality of its food.

He also felt that entomologists usually studied insect populations when they are at or near outbreak levels - this hampers any study of what part of the normal controlling complex went awry and it particularly obscures any basic effects of climate.

To assess climatic influence correctly, it is necessary to study climatic variation during the period preceding or coincident with the beginning of an outbreak.

Wellington (1954) proposed a theory of "climatic release" of a small indigenous population - "in a region where a species exists in small numbers, and in which biotic conditions already favor population growth, no initial increase may occur until seasonal climatic control is relaxed: however, favorable weather may have to recur several years in succession before a major increase in the population occurs."

Wellington believes strongly that serious consideration of meteorological factors have been ignored because of widespread belief that climate is relatively static, so that observed fluctuations are simply random fluctuations about a mean.

Many ecologists warned that weather in the microenvironment differs from the general weather and therefore could not be studied with classical instrumentation. However, particular kinds of microweather are produced by characteristic kinds of general weather. Wellington referred to his synoptic approach to studies of insects and climate: In an area where the insect occurs (a) select two habitats that are most dissimilar; (b) place standard weather bureau instrumentation in the more exposed site; (c) when certain types of weather occur such as frontal systems or air mass passages, an intensive meteorological program is initiated in each area - this gives a range of micrometeorological conditions associated with each weather type; and (d) therefore, only a few days' data/weather type/season are accumulated.

A good example of an application of this approach is the study of the spruce budworm and forest tent caterpillar in the Boreal forests of North America (Wellington 1952). It was noted that spruce budworm outbreaks were preceded by outbreaks of the forest tent caterpillar. Ideal conditions for spruce budworm development occur when the air is relatively dry and clear. Laboratory tests also indicated that the larvae preferred area of

high evaporation. In the field they feed within webbed feeding shelters in buds and expanding shoots. Evaporation in these shelters is optimal when sunny, dry weather persists.

Population increases occurred when the number of cyclonic passages in the late spring and summer are below average and the majority of air masses are of polar continental or polar maritime origin. A southward shift of the whole circulation process is probably influenced by the jet stream in that area.

Conversely, forest tent caterpillar outbreaks occurred when there was a northward displacement of the circulation complex so that an above average number of air masses of southern or southwestern origin occurred in the area. This results in humid, partly cloudy weather during the larval stage and this was shown to be optimal for development and survival of the forest tent caterpillar.

Greenbank (1956, 1957) later verified this phenomenon for the spruce budworm in the Province of New Brunswick. New Brunswick lies in a major exit channel for North American weather systems. Periodic shifts in storm tracks cause considerable annual variations in regional climate. Until recently, there had been two major outbreaks of the budworm in this century. The 1912 outbreak was general to the province and was preceded by a few years of early summer drought. The 1949 outbreak was confined to northern New Brunswick and only that part of the province was subject to earlier drought. He found that a complicating factor was the mass movement of gravid females that were transported by cold frontal storms. This "instant outbreak" potential is now being intensively investigated in New Brunswick.

Now, I would like to discuss some more recent examples of weather affecting forest insect populations.

One of the most interesting recent approaches is a study of the interaction between lodgepole pine, the mountain pine beetle, and its associated blue stain fungi in western Canada (Safranyik et al. 1975). They developed a map of hazard ratings for western Canada based on climatic variables. It's estimated that the mountain pine beetle destroys about 3% of the average annual cut of lodgepole pine. However, the monetary loss is far greater than the volume loss because high-value trees (ca. 80 yrs or 8-10" dbh) are usually killed by the beetle and the fungi.

A map of outbreak chance was developed from the analysis of six climatic variables

measured at 42 locations for a period of 20 years.

A. Principal variables

- P₁: More than 550 degree-days heat accumulation above 42 degrees F. from August 1 to the end of the effective growing season (Boughner 1964) and more than 1,500 degree-days heat accumulation within the effective growing season from August 1 to July 31 the following year.
- P₂: Minimum winter temperatures higher than -40 degrees F.
- P₃: Average maximum August temperatures greater than or equal to 65 degrees F.
- P₄: Total precipitation during April, May, and June less than the long-term average for these months.

B. Modifying variables

- X₁ = Variability of growing season precipitation (coefficient of variation).
- X₂ = Average annual water deficit (National Atlas of Canada, 1970).

P₁ was defined on the basis of the following assumptions: 1,500 degree-days is an index of minimum heat accumulation required by beetles between successive peak flights, and 550 degree-days was taken as the minimum heat requirement from peak flight to 50 percent hatching of eggs. If neither of these heat requirements are met, population buildup cannot occur because broods will either be forced into a two-year cycle and overwinter in the pupal and/or adult stages or the majority of broods will have to overwinter as eggs. Eggs, pupae, and adults are more susceptible to freezing than the larvae which is the normal overwintering stage.

In defining P₂, -40°F was taken as the minimum air temperature threshold for population increase because complete mortality results when larvae are exposed to temperatures from -30 to -36°F. for short periods.

In defining P₃, it was assumed that when the frequency of hourly maximum temperatures above 70°F. during August is 5% or less, an extended beetle flight period will result and attack success will decline; flight commonly occurs at temperatures above 70°F.

P₄ is a measure of tree response and of

favorable conditions for beetle development and survival during spring. This variable was established on the basis that high beetle activity followed periods within two or more consecutive years of below average precipitation from April to May over large areas in western Canada.

X1, variability of growing season precipitation, has important effects on the host tree and beetle-fungi complex. The average annual water deficit (X_2) effects the growing conditions for lodgepole pine.

The hazard map, when compared to the distribution and frequency of past outbreaks, is a reasonable representation of the outbreak potential for western Canada. What about the usefulness of this approach for management? Within the two lowest outbreak chance classes, the beetle threat in mature stands is low and therefore the chance of stand depletion is not included in long-range management plans. In areas with the three highest outbreak classes, formulation of long-range management goals and silvicultural practices should include the probability and severity of stand depletion by the beetle. Rotation age can be reduced on better sites, stands can be converted to successional types, or one can recommend clearcutting and regeneration to mixed age classes of lodgepole pine.

The relevance of this approach is that meteorological variables that are biologically meaningful are being used to develop a realistic predictive model that will aid in management decisions.

I would like to turn now to a very different insect problem -- the balsam woolly aphid, a sapsucking insect that infests all true firs. This aphid feeds on the bark cortex of all parts of the tree from stem to twigs and results in severe gouting and eventually tree mortality. Greenbank (1970) described how the ecological characteristics of the insect and the prevailing climate determine the severity of infestation of balsam fir in the Maritime Provinces of Canada. The climate of the Maritimes changes markedly from the coast inland, and Greenbank characterized 3 bioclimatic regions: (2) the coastal regions are maritime climate with mild winters and cool summers; (b) northwest New Brunswick is continental climate with extremely cold winters; (c) central New Brunswick is transitional with periods of mild winters broken by occasional cold winters. He used three parameters to characterize these regions: (a) total summer heat in degree days above 42°F. during the growing season. This determines the number of generations/year and will vary from one to three in the Maritimes, and in the warmer

regions of south-central New Brunswick and Nova Scotia where 3000 degree days may occur. This was calculated from field development data; (b) plotted probabilities of winter temperatures over a period of years -- 15 to -25°F. is lethal to the diapausing first stage nymphs; (c) snow cover which is a survival mechanism for those insects that overwinter at the base of trees.

Laboratory and field studies were conducted simultaneously and included thermistor measurement of overwintering temperatures below the snowline and on the trunk and bark scales on branches.

Conclusions:

1. In Maritime areas, i.e. the coastal areas of New Brunswick and Nova Scotia, twig and stem attack occur together and all trees are eventually killed or severely gouted. Survival at the upper strata results in more windblown dispersal and therefore more extensive damage.
2. In continental regions (North Central and Northwest New Brunswick) where severe winters occur, surviving populations are limited to the base of trees below the snowline. With 6" of snow cover, bark temperatures were not recorded below 0°F., while air temperatures above the snowline frequently were recorded down to -20°F. Tree mortality accumulated slowly and gouting was negligible. Infestations remain small and isolated, and dispersal is negligible because of overwintering mortality at the upper strata.
3. In transitional regions (10-60 miles inland) populations behave as in Maritime area when mild winters occur. However, periodic severe winters occur every few years and this tends to decimate the aphid population so that trees may recover.

One of the most important aspects of the relationship between weather and the population dynamics of forest insects is the interaction through the host plant. It's amazing to me that forest entomologists are finally getting around to looking at the complete system - the interaction between insect, host plant, and weather. There has been a resurgence in this research area and it has been long overdue. Though T.C.R. White (1969) has only recently published on weather-induced stress of trees associated with outbreaks of forest insects, the idea is not new. Charles Darwin, in his classic "The Origin of Species" in 1859 stated and I quote "...in the struggle for existence the indirect effect of weather operating through food supply is more important than its direct influence on the animals themselves." It has taken us a long time to investigate this hypothesis.

Much has been written about the interaction between weather and food, but the emphasis has been placed on changes in the distribution and abundance of food during different seasons (Wellington 1957). Recent research suggest that the effect of weather on the quality of food may be the controlling factor in many of our insect problems (White 1974, 1976).

There have been two widespread and severe outbreaks of a psyllid (sapsucking insect) on eucalyptus in Australia. Outbreak periods were characterized by unusually wet winters and unusually dry summers. Soils in this area are poorly-drained and are susceptible to waterlogging in winter and to drought in the summer.

White developed a "stress index" obtained by transforming the rainfalls for summer (December-February) and for winter (April-October) each year to standard normal deviates about their means. The relationship of these values to the long-term mean is not relevant--the contrast between winter and summer in the same year is important. Stress index was positive when the summer was dry relative to the preceding winter.

There were two periods since 1900 when the stress index for south-eastern Australia increased rapidly to high positive values - and that was when outbreaks occurred. When he plotted data for the rest of Australia, the same relationship held up quite well. Between outbreaks, population of psyllids became so sparse that only a few persisted on individual trees.

White suggests that the causal explanation of why outbreaks are related to stress indices is as follows: when a plant is stressed, especially water stressed, there is a complex change in the quantity, distribution and composition of its nitrogen content. A general decrease in protein synthesis and conversion of existing protein into water-soluble forms takes place. There is an increase in total nitrogen in aerial parts of plants and a decrease in the roots in response to dehydration. This may result in either a general quantitative increase in the amount of nitrogenous food available or in the relative proportions of one or more of the amino acids in the phloem sap. Nitrogenous food is essential for young, rapidly developing animals.

White then demonstrated in the laboratory that the phloem sap of healthy trees (unstressed) is actually unsuitable for survival of immature psyllids. They would insert their stylets and

initiate feeding but eventually died with the stylets still inserted.

White (1974, 1976) has also applied this weather-stress hypothesis to explain outbreaks of looper caterpillars in New Zealand and of other defoliating insects. I am convinced that this explanation is sound although there may be more involved than a simple nitrogen relationship in the host. The most critical period for most defoliating insects is when they must establish on foliage after they hatch and/or disperse in the spring. We assume that if foliage is abundant, it is acceptable to the insect. I suspect this is not true although we lack positive proof to substantiate this theory. For example, in our study of the gypsy moth, we often predict from egg mass counts that complete defoliation is inevitable - however, many times defoliation does not result and we have not been able to explain why - certainly biotic agents have not been responsible. If in fact the foliage was not acceptable, the newly-hatched larvae would eventually starve, and we have no way of quantifying such an occurrence.

White's stress index may be an oversimplified approach. Recently Kalkstein (1976) attempted to evaluate effects of climatic stress upon outbreaks of the southern pine beetle. He suggested that climatic variables should be expressed as variables derived from the Thornwaite climatic water balance. This considers the soil moisture factor and also evaluates the potential evapotranspiration, which is an estimate of the amount of moisture lost from a vegetation covered surface. This is probably a much more accurate and realistic way to evaluate stress on a tree or plant.

I did want to emphasize one good example of the effect of weather on insect behavior, specifically dispersal. Many of our major forest insect pests disperse passively as windblown larvae on silken threads - this includes the spruce budworm, gypsy moth, and Douglas-fir tussock moth. In my research on dispersal of gypsy moth larvae, we encountered a situation in the field where dispersal in the spring of 1974 was literally shut-down. We were monitoring egg hatch and had established a series of elevated samplers to entrap dispersing larvae. However, just as peak hatch occurred, a weather system moved through the study area resulting in low temperatures and cloudy, inhibited activity and dispersal behavior. Dispersal never did commence and we caught few larvae in our traps. This has a deleterious effect on survival and also retards redistribution and spread of the larvae in the general area.

Though I have limited my discussion to forest insects, the best example of weather affecting dispersal of insects involves aphids and leafhoppers that transmit diseases to cereal crops. Wallin et al. (1967) demonstrated that low-level jet winds that flow from the southern plains into the North Central states in April and May, are responsible for the mass transport of these species over hundreds of miles.

CONCLUSIONS

A synoptic biometeorological approach should be included in our studies of the population dynamics of forest insects. Additionally, simultaneous studies on the effects of stress on the quality of the host should also be included in such investigations. The examples that I have discussed in this presentation suggest that weather does affect insect populations in many ways. Why have biometeorological investigations been so seldom employed in the past? I have some observations and some suggestions.

1. We are always looking at the data after the fact. Standard weather data can usually be obtained from the past, but our quantitative measure of historical insect population data has been inadequate and is usually only an indication of what really occurred.

2. Analyses of historical weather and insect population data can produce predictive models and demonstrate cause-effect relationships; however simultaneous field and laboratory studies are needed to identify the mechanisms through which weather is affecting the population.

3. Support has been lacking for long-term research. Even the USDA combined forest pest programs on the gypsy moth, tussock moth and southern pine beetle, which have been a tremendous stimulus to accelerate research and to attain specific objectives, cannot provide the solution to this problem because they are funded for a 3-5 year duration. We need a continuing research program in order to obtain the quantity and quality of data required.

4. An interdisciplinary approach is needed. I propose that our lack of progress in this field stems from the fact that entomologists have been uncomfortable with meteorological data, its interpretation and the instrumentation and methodology that may be required to obtain it. Similarly, most are not equipped to conduct companion studies in tree physiology or insect biochemistry. An entomologist, working with a meteorologist and

a biochemist or physiologist should be able to design a research program that considers the effect of changing weather on the quality of both the host and the insect population that is dependent upon it for survival.

LITERATURE CITED

- Greenbank, D.O.
1956. The role of climate and dispersal in the initiation of outbreaks of the spruce budworm in New Brunswick. I. The role of climate. *Can. J. Zool.* 34:453-476.
1957. The role of climate and dispersal in the initiation of outbreaks of the spruce budworm in New Brunswick. II. The role of dispersal. *Can. J. Zool.* 35:385-403.
1970. Climate and the ecology of the balsam woolly aphid. *Can. Entomol.* 102(S):546-578.
- Hopkins, A. D.
1919. The bioclimatic law as applied to entomological research and farm practice. *The Scientific Monthly* 8(32):496-513.
- Kalkstein, L. S.
1976. Effects of climatic stress upon outbreaks of the southern pine beetle. *Environ. Entomol.* 5(4):653-658.
- Safranyik, L., D. M. Shrimpton, and H. S. Whitney
1975. An interpretation of the interaction between lodgepole pine, the mountain pine beetle, and its associated blue stain fungi in Western Canada. *In* Management of lodgepole pine ecosystems symposium proceedings. 406-428. Wash. St. Univ. Coop. Ext. Serv. Pullman.
- Varley, G. C., G. R. Gradwell, and M. P. Hassell
1974. Insect population ecology: an analytical approach. Univ. Calif. Press, 212 p.
- Wallin, J. R.
1967. Low-level jet winds, early cereal aphid and barley yellow dwarf detection in larva. *Plant. Dis. Repr.* 51:527-530.
- Wellington, W. G.
1952. Air-mass climatology of Ontario North of Lake Huron and Lake Superior before outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clem.) and the forest tent caterpillar, *Malacosoma disstria* (Hbn.) (Lepidoptera: Lortricidae; Lasiocampidae) *Can. J. Zool.* 30:114-127
1954. Atmospheric circulation processes and insect ecology. *Can. Entomol.* 86(7): 312-333.
1957. The synoptic approach to studies of insects and climate. *Ann. Rev. Entomol.* 2:143-162.

_____, C. R. Sullivan, and G. W. Green.

1966. Biometeorological research in Canadian forest entomology -- A review.

Int. J. Biometeorol. 10(1):3-15

D. Peters and L. C. Johnson

White, T. C. R.

1969. An index to measure weather-induced stress of trees associated with outbreaks of psyllids in Australia. Ecology 50:905-909.

1974. A hypothesis to explain outbreaks of looper caterpillars, with special reference to populations of Selidosema suavis in a plantation of Pinus radiata in New Zealand. Oecologia (Berl.) 16:279-301.

1976. Weather, food, and plagues of locusts. Oecologia (Berl.) 22:119-134.

Meteorology and Pesticide Application¹

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Abstract.--Problems in aerial application of pesticides to forests are described with special reference to meteorological factors. Field experiments, pilot projects, and operational projects are considered. All require weather forecasting to schedule spraying. Needs describing equipment and methods to control or measure spray behavior from release until arrival at the ultimate target are discussed. Figures are presented with several constraints that define a spray window showing best drop-size range and atmospheric conditions for spraying. The constraints have not been established quantitatively and show the need for additional meteorological research and development. A need has been demonstrated for a spraying strategist, who may or may not be a meteorologist, but will require new tools from the meteorologist.

INTRODUCTION

I've been involved in developing equipment for aerial application of insecticides in western forests since 1964. I certainly welcome an opportunity to share some thoughts I have developed over this period, particularly in the unfilled needs in delivering pesticides from the air to the forest canopy.

I would like to begin with a quotation from Dr. Peter Southwell, who is with the School of Engineering, University of Guelph, Ontario, Canada. This is a quotation from an address given by Dr. Southwell at the Fifth International Agricultural Aviation Congress in Warwickshire, England:

"The evidence suggests that precise definition of target surface and thence prescription of the optimum droplet size and number of droplets for a particular circumstance could lead to tremendous increases in the efficiency of pesticides usage. In order to achieve this, though, we need to understand a great deal more about the spatial dynamics of insects, about micrometeorology within and above crop canopies

and about the behavior of droplets. The first of these paths to progress is the preserve of the biologists amongst us, and their colleagues. The second emphasizes the urgent need for a much greater input to bio-aeronautics by the meteorologists. The third path lies in the territory of our physicists and aerodynamicist friends, and I hope they will be persuaded to collaborate with the meteorologists in studying the performance of foliage canopies as a droplet filtration system."

Dr. Southwell is speaking about aerial application in general, including agricultural crops, forestry, and public health, but I think that his remarks are particularly pertinent to our forestry application. Dr. Southwell very pointedly mentions the need for interdisciplinary cooperation. He points out not only the need, but the possibility of tremendous progress. This progress, however, is dependent on interdisciplinary cooperation and he especially emphasizes the need for the meteorologists as well as the physicists and aerodynamicists.

Here are some observations on the state of the art in aerial application within the United States. I do not know of any forestry aerial application group within the United States, conducting comprehensive research and development, that has a full-time meteorologist on its staff. Some of the organizations doing what I would call comprehensive research and development have people from other disciplines

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who work in the field of meteorology, who take meteorological measurements, who attempt meteorological interpretations, but are not professional meteorologists.

We know that one of the most important aspects of aerial application in forestry is selection of proper drop size. We also know that selection of proper drop size and production of that particular drop is one of the most, I might say controversial, but perhaps I should say most discussed questions. For most forest insects and pesticides the entomologist cannot tell us the precise drop size that he would like to deliver to the target. Even if the entomologist could specify the drop size, the meteorologists and physicists cannot tell us precisely how to deliver that drop size to the target; and even if the meteorologists and physicists were able to tell us how to deliver this drop size, the engineer cannot tell us how to produce this drop size and what the effect of aircraft wake is upon delivery of the drop.

Dr. Southwell says that there is a tremendous area for progress. I mentioned some of the lack of progress and I would like to continue to discuss the problems from the standpoint of delivery of insecticides. I would like to go on to a discussion of some of the progress made in solving these problems and how this variety of problems might be organized for an efficient attack by those biologists, scientists, and engineers. Finally, I would like to draw a scenario of how the future spray project might be conducted when you gentlemen and your colleagues have solved some of these problems and have made the solutions available to the forester who is charged with the responsibility for managing the insect population.

I am not here to ask you as meteorologists and specialists in fluid dynamics to solve all of the aerial application problems; I am certain that efficient solution of the meteorologically related problems cannot be attempted without some knowledge and appreciation of the variety of problems that beset the aerial applicator. Therefore, I am going to present an entire array of problems and leave it to your judgment which ones you feel the meteorologists can most efficiently attack.

PROBLEMS AND PITFALLS

Chemical sprays have been used to control insect and disease in agricultural crops for

many years. Literature abounds with results of research and new equipment as well as techniques developed for spraying cropland. From the standpoint of control, aerial chemical spraying of agricultural cropland has been very successful. Techniques and equipment developed for aerial spraying of croplands have been adapted to aerial spraying of the forests; sometimes successfully and sometimes unsuccessfully. Forest spraying presents many problems not found in normal agricultural spraying: The target is a dense three-dimensional canopy; the terrain is usually irregular; convective winds are frequently prevalent; the aircraft cannot fly close to the crop; the crop is usually a low-value crop compared to agricultural crops; there is frequently high-quality water nearby; there is difficulty in marking ground locations.

Let us look at some problems facing an applicator spraying forest insect larvae in the western United States:

1. Because of the concentrating effect of mountain valleys and canyons, significant concentrations of insecticides can be carried several miles.

2. Instead of falling a few feet as in the case of cotton spraying, forest insecticides must travel 50 to 250 feet vertically to reach a target. Losses, due to evaporation, become more significant both in terms of greater drift and loss of insecticide.

3. The dense forest foliage may capture all of the insecticide within a few feet, resulting in only one side of the tree being sprayed.

4. On the other hand the drops may be so small that they are deflected around the target by aerodynamic forces.

5. Some lateral displacement of the spray is beneficial, but if the displacement is excessive the applicator cannot predict where it will reach the forest and has lost effective control of the spray.

6. In his zeal to prevent excessive lateral displacement, the applicator may select drops so large that too few numbers of drops are available for effective coverage.

7. It is difficult to fly evenly spaced swaths over large, irregular tracts of forest having few roads or identifying boundaries.

8. Steep slopes present several problems. The actual surface area is greater than shown on a map, the downhill side of the boom may be 50 feet higher above the trees than the uphill side of the boom. Flight path and direction are limited because the aircraft cannot climb steep slopes, instead the aircraft usually flies contours.

9. Rough, irregular terrain is usually associated with steep slopes. If the applicator flies a level path his altitude above the terrain varies continuously; if instead he follows the terrain, roller coaster fashion, his speed and application rate vary continuously.

10. In an effort to obtain better coverage, the applicator may increase the volume of insecticide carrier without giving adequate consideration to the lethal drop size, requiring hundreds of drops to kill a larva rather than one drop.

11. The aircraft wake, whether it be wingtip and propellor vortices from a fixed-wing or rotor vortices from a helicopter are a major influence on the spray behavior. Small drops are entrained in this cloud and transported in a manner similar to smoke ring movement. Other larger drops fall independently of the vortex but are not readily visible. Thus, the applicator may be misled by observing the visible cloud.

12. In 2 hours of morning spraying the stability conditions usually vary from spraying under an inversion to neutral or unstable condition. The applicator will not be aware of these changes.

SOLVING APPLICATION PROBLEMS EFFICIENTLY

To see the contributions that meteorology as a science can make towards these problems I think it is well to establish some levels of usage. The natural development for research leading toward applications in the field of insecticides within the Forest Service begins with laboratory screening. The second step is field experiments with the most promising laboratory materials taken to the field and evaluated on a small scale within the forest. Small scale is generally in the 40-acre spray block category. The next step would be a pilot control project. Here the promising candidates from the field experiments are taken to the field and applied on a large enough scale to simulate the problems that

would be encountered in a control project. The equipment must be large enough to be used on a larger scale control project. Then candidates that have passed these phases, have met the requirements of the Environmental Protection Agency, the Department of Agriculture, and the Forest Service are available for control projects which are a management tool of the forester.

At the first level of usage, laboratory screening, we see a place for the meteorologist in assisting the biologist in the design, construction, and operation of the spray chambers and in the conduct of wind tunnel experiments. In field experiments the meteorologist can be expected to play a very important role because usually we have a large number of chemicals or pesticides, the plots are small, and there is a need to demonstrate that comparisons of various pesticides have been conducted under sufficiently similar meteorological conditions to provide a proper comparison. Since the spray plots are small, delivering the material to a small area is frequently much more of a problem than when substantial amount of drift and swath overlap is useful on a large spray project.

In a pilot control project, one of the important roles served by the meteorologists is in providing weather forecasting. These projects are usually quite expensive and yet they provide no direct economic benefit to the forest manager because they are not established to control insects, so the minimization of cost is very important. The meteorologist can give us accurate weather predictions so that the materials can be applied under the desired conditions and the mobilization of equipment and manpower is done on an efficient basis.

A further important role is as an advisor to the project officer on strategy and tactics for delivering the insecticides. This has been a role that we have seldom seen a meteorologist in but one that I think is going to be of increasing importance.

The control project itself has all of the same problems that a pilot control project has, but in addition it is probably more subject to public criticism and scrutiny. It involves dispersion of much greater amounts of pesticides, therefore every phase of the application from delivering the minimum amount of insecticide to a given area and concern with off-target risks are extremely important. Again there is a role for a spray strategist.

NEED FOR RESEARCH AND DEVELOPMENT IN EQUIPMENT AND METHODS

We do not know all of the things that need to be measured in the field and we do not know how frequently or where they need to be measured. However, we can make some general statements.

Battery-powered Equipment

Equipment should be portable and since we need information from several locations it should be as inexpensive as possible, compatible with the quality of information. There is probably a need for a telemetry system that can accumulate real time data from a variety of points within a spray area and transmit it to the project director. We also know that simply making meteorological measurements at or near the ground level is not sufficient; that there is a definite need to have some information in the regions above the canopy and near the release line of the aircraft. We've worked with two types of system here at the Equipment Development Center in Missoula: Tethered balloons which either transmit information via a wire or via a radio signal. We've also used portable towers and it has been my own experience that the towers that are available are too slow, too cumbersome, not sufficiently portable to be useful. My own opinion is that for measurements in the region above the canopy, tethered balloons are definitely preferred.

Some of the things that affect spray behavior are turbulence, windspeed, wind direction, and temperature; here again not just at ground level but the entire region from release at the aircraft to the impaction on the target.

Weather Forecasting

Under Methods Development, the first item to consider is forecasting. For most of us nonmeteorologists when we think of meteorology we think of weather forecasting. As a result of the efforts of the combined forestry and meteorology groups there are available the tools and the administrative procedures that have been developed in connection with fire control to provide weather forecasting service to aerial spray applications. We have found fire weather forecasting to work extremely well. The quality of weather forecasts is going to depend generally upon developments on a much broader scale in the state of the art in knowledge in forecasting weather. So perhaps one of the biggest improvements that might be made is in providing additional information to the weather forecaster. Can we provide additional, faster, more specific information about the particular spray sites to the weather

forecaster so that he can give us improved forecasts? Generally there are two periods when we expect a forecast from the meteorologist--(1) in the evening before spray day, final decisions are made as to what areas will be sprayed, where the people will be deployed, how much material will be mixed, and at this point it is very important to have the most up-to-date forecast information for decisionmaking about the following day's activities; and (2) just prior to spraying. Now, unfortunately, this usually occurs at 4:00 or 5:00 in the morning. But at this point new weather patterns may have developed and a decision must be made quickly on whether to spray or not to spray that day. So it's very important that we have the weather forecaster and his best knowledge and judgment available to us at that particular time.

Air-to-Air Spraying

I would like to touch briefly on air-to-air spraying. To the best of my knowledge there has been no air-to-air spraying of forest insects conducted within the United States. However, an extensive research program is being carried out in New Brunswick, Canada. The basis for the air-to-air spraying of the spruce budworm is to spray the adult moth before she can lay her eggs in a previously uncontaminated area. It involves radar tracking of clouds of moths, as well as the tracking of wind systems, followed by predictions of where within the air space to deliver a swath of pesticide that will make contact with the adult moth in the air. In this type of operation even more than in normal spraying, the close cooperation between the biologists, meteorologists, engineers, and aerodynamicists is very important. On this topic I would leave you with the question that if air-to-air spraying of the spruce budworm in the Province of New Brunswick is successful, should the similar technique be investigated for application within the United States, both in eastern forests and in our western mountainous region? Here the most important starting point in the air-to-air spraying is understanding the activities of the moth as related to time, space, and meteorological conditions. Therefore I think we probably could expect the leadership to come from the biologists.

Control of Drift

There has been a large amount of research done in the control of spray drift and contamination of nontarget areas by the agricultural researchers. Most of these tests have been done in relatively flat agricultural areas. Within our mountainous terrain I am sure that many of the same techniques can be applied; certainly the same type of monitoring equipment, but within the mountainous regions we're sure that insecticide drift is concentrated by the

channeling of airflow through canyons and valleys.

This would appear to be a formidable array of problems. It is also a tribute to the aerial applicators that they do carry on successful spray projects despite these problems and the lack of knowledge in some of the areas.

AN APPROACH TO ORGANIZING THESE PROBLEMS

In figure 1 we show the effect of a droplet being carried so far away that it is essentially beyond the control of the applicator. Here we have a plot of droplet diameters versus windspeed above the canopy. The shaded area to the left is the area in which the drops would be carried too far. I've somewhat arbitrarily chosen 1,000 feet as too far. In some circumstances it would be more and in some less. We see that there is an area on the right within which the drops can be contained and an area to the left which we want to avoid.

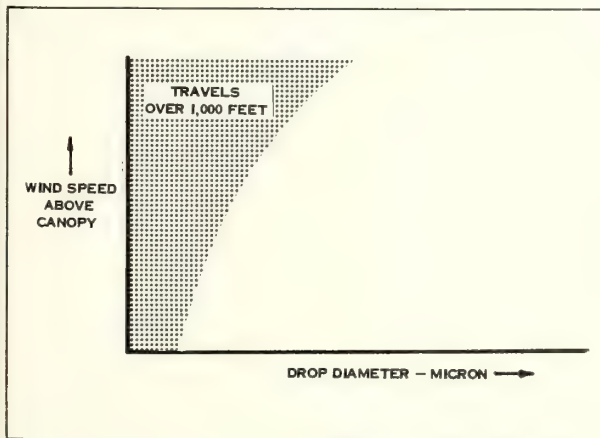


Figure 1.--Excessive swath displacement.

Figure 2 shows another aspect of the problem. This is a representation of the fact that the droplets will not penetrate the canopy. That is they will be very effectively filtered out by the first foliage that is encountered and cannot be uniformly deposited throughout the canopy. In this case the permissible area is on the left. The avoided area is on the right and again it's a plot of drop diameter versus windspeed above the canopy.

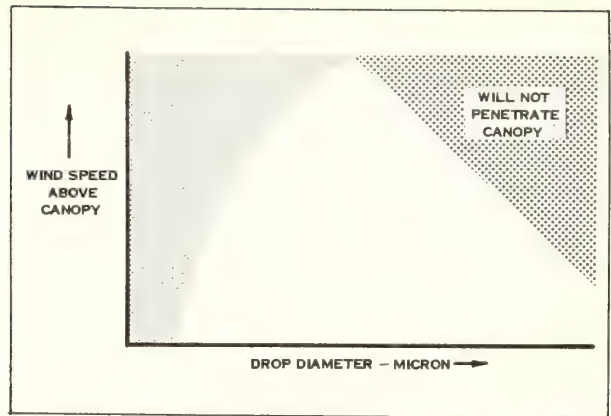


Figure 2.--Drops too large to penetrate canopy.

In figure 3 we have the same coordinates, but we demonstrate the area in which there are not sufficient drops available to provide adequate coverage. This is of course based on some reasonable amount of total volume of material being delivered. Again the area on the left is suitable; the area on the right is to be avoided.

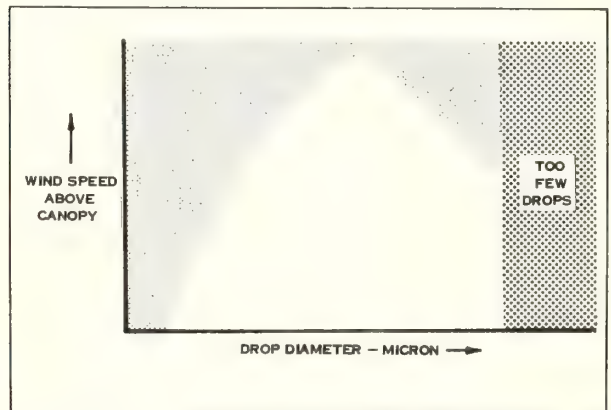


Figure 3.--Too few drops for coverage.

Figure 4 shows relationship between wind-speed and drop size for one value of turbulence. In figure 5 we show the area where because the windspeed is too low and the drops are too small, they will not impinge on the target. In this case the target might be considered to be either foliage or an insect. The area on the right is permissible; the area on the left is to be avoided.

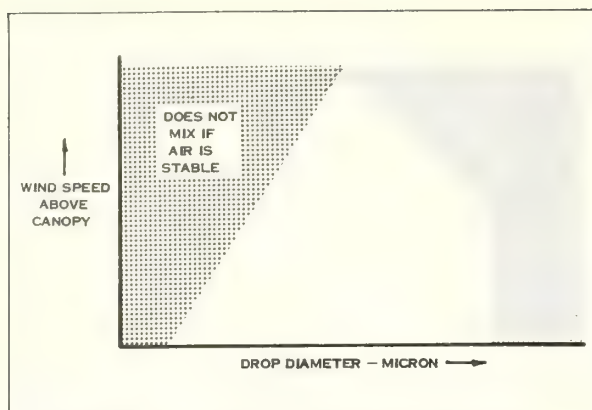


Figure 4.--Lack of turbulence affects deposition.

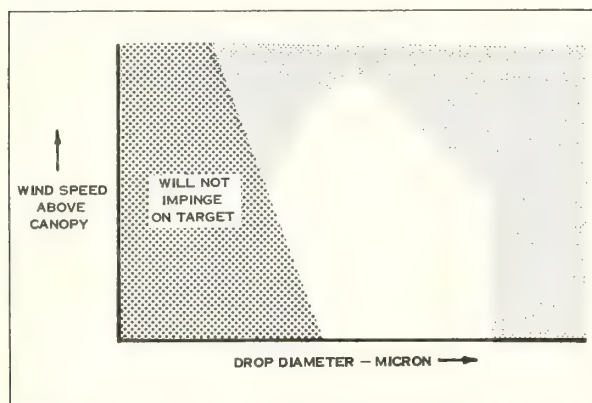


Figure 5.--Drops are deflected around target.

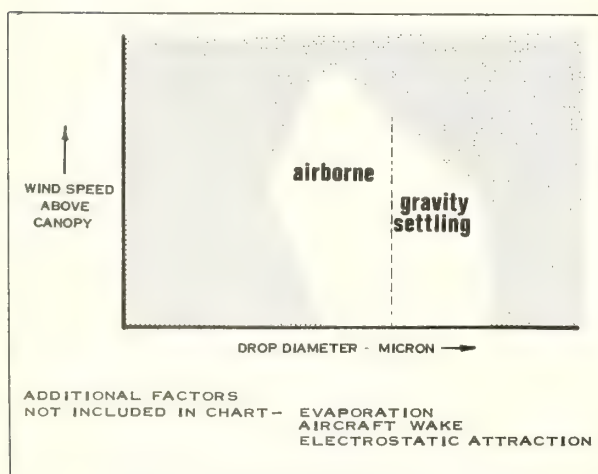


Figure 6.--Envelope of optimum drop size.

In figure 6 we chart all of these curves on the same graph we find that in the center is the permissible area bounded by several areas that are not useful. Here again notice that we have not placed any values on drop diameter or values on windspeed. However, we know a general range for these values and demonstrate that when all of these constraints are considered together there is one open area that is permissible. We also feel pretty certain that this permissible area is broken up into two areas. On the left side the drops are so small that they are principally airborne. Their terminal falling velocity is so low that they are essentially carried wherever the wind takes them; whereas the right side represents larger drops. These large drops are affected by air movements but their arrival at the target is primarily through gravitational settling.

These figures demonstrate the possibility of a rational approach to this entire problem where a multitude of factors can be considered together and it also shows that the problem is complicated by the fact that the physical behavior of the drops in the optimum range is essentially governed by different sets of equations; one being the airborne particles and the other being the particles subject primarily to gravitational settling. I would also like to point out that there are other factors that affect the optimum drop range that are not included: Evaporation, effect of aircraft wake, and the electrostatic attraction of the ground and foliage for the drops.

Spray Strategist

There are some very severe constraints imposed upon a large operational spray project. The period during which the insect is susceptible to the material being applied is relatively short. The time of day and number of days with weather suitable for spraying may be relatively brief. The number and types of aircraft that are available for a short duration project are definitely limited. These are constraints that very little can be done about. However, at the same time, by understanding the physical phenomenon that are governed by basic scientific principles we can spray more effectively, reduce damage to the environment, and in some cases increase the period of time available for spraying.

I feel that the principles involved and the expertise are sufficiently complex to warrant the training of a spray strategist. I'm not suggesting that the spray strategist be a primary title, nor am I suggesting that the person need to be a meteorologist or physicist or engineer. However, I believe that the physicists, aerodynamicists, engineers,

meteorologists, entomologists must develop the body of knowledge and ultimately provide training to a spray strategist who will be available as a staff position to a project control officer.

Sample Spray Project

During the Northern Region pilot control project for spruce budworm in western Montana in June 1976, we applied some of the principles of spray strategy. We think that the principles were applied successfully and contributed to the success of that particular spray project. The principles and body of knowledge that are necessary for good spray strategy have not been completely developed. However, I would like to give you some examples of how spray strategy might be employed.

This was a spray project that was conducted on National Forest land that was rough, steep, irregular terrain. Spraying followed the conventional practice of spraying early in the morning and continuing spraying until either a plot was completed (these plots were about 2,000 acres), or until the winds appeared to be unfavorable. The spraying was done with a turbine-powered helicopter with rotary atomizers.

Now, some examples of what we did:

- We made a study of seasonal weather patterns in the area.
- The pilot was required to fly a reconnaissance of each spray area prior to the day of spraying, and submit a map of his selected direction, length and order of spray swaths.
- A meteorologist reviewed the flight plan and gave the pilot an estimate of wind-speed and direction and estimates of when windspeed and direction would change.
- Ridges were sprayed during the first 30 minutes of daylight when downslope winds were in effect. It is almost impossible to spray ridges after upslope winds are well developed.

- Windspeeds were measured both at ground level and 50 feet above the canopy during spraying.
- Whenever possible the aircraft was flown crosswind to enhance overlapping of swaths.
- Based on model calculations the pilot was instructed how much to offset from the spray boundary to compensate for swath displacement.
- Special attention was given to areas that had converging gradient and slope wind fields.
- Actual swaths flown by the spray aircraft were plotted on an aerial photo by an observer in a chase helicopter.

These are a few of the things that can be done based on today's knowledge and equipment.

For the future one can imagine many things within the realm of today's technology.

- Electronic guidance for spray aircraft that also operates a plotter at ground station to show swath patterns on a map.
- Computer generated maps of predicted drainage wind flows for each hour of the day.
- Several remote locations where windspeed, wind direction and temperature are measured and automatically transmitted to a central station.
- Spray equipment that can be quickly adjusted to provide drop sizes to suit a newly observed meteorological condition.
- A remote sensing monitor for detecting excessive off-site spray drift.
- But perhaps most important, a well trained spray strategist who can access this information, interpret the information and provide the project director the best guidance on how to deploy the spray equipment.

CONCLUSIONS

1. There is a great potential for improving aerial delivery of insecticides.
2. Most of the major problems are readily identifiable.
3. Technology for solution of the problems exists but must be applied in a creative, innovative manner.
4. Timely efficient solutions require a comprehensive program directing the efforts of an interdisciplinary team.

In closing I would like to once more quote Dr. Southwell:

"We need to keep our feet on the ground, as well as our head in the clouds."

A Canopy Penetration Model for Aerially Disseminated Insecticide Spray Released Above Coniferous Forests¹

Bruce R. Grim²/

John W. Barry³/

Abstract.--A mathematical simulation model has been developed which predicts the penetration and vertical distribution of aerially applied insecticides through coniferous canopies. Model input includes forest and tree types, spray characteristics, and meteorology. Plots were constructed of model predictions and observed data from a U.S. Forest Service pilot project. Model behavior is relatively consistent with observed data.

INTRODUCTION

Previous experience in the development and implementation of aerial dissemination techniques for coarse aerosols and sprays has disclosed the need to minimize spray drift and increase the efficiency of spraying in terms of cost and insect control. Effective use of mathematical modeling techniques, which establish relationships between the many factors effecting spray operation, has resulted in the capability to optimize flight patterns and spray strategy, and to predict the success or failure of a proposed spray operation.

Penetration of forests by fine aerosols has been addressed by Calder (1961); however, penetration of forests by droplets with an appreciable fall velocity has had limited attention. A theoretical study by Johnstone, Winche, and Smith (1947) addressed the problem of droplet impaction on vertical and horizontal surfaces. The study, however, did not attempt to relate specific forest parameters (i.e. tree stand, density, foliage density, tree height) to the amount of material penetrating the canopy.

The U.S. Army Dugway Proving Ground (1971) prepared a prediction study with a line source model for the U.S. Forest Service. The model accurately predicted that the amount of insecticide material planned for release over the target was insufficient to produce the desired insect mortality. Prior to field trials conducted by the U.S.F.S. in the Bitterroot National Forest during 1973, (Dumbauld and Cramer 1973) prepared predictions of downwind deposition of insecticides. These predictions were used successfully by the project officer in deciding where the release should start and end to achieve maximum deposition within the spray plot. These predictions were for above-canopy deposition. Problems related to physical penetration of the canopy by the insecticide were not studied, as there was no model available at that time.

The objective of this study was to develop a model for predicting the penetration of insecticide sprays through a coniferous forest using forest characteristics as input to the model.

METHOD

This study relates canopy penetration of droplets 50 micrometers and larger in diameter to forest characteristics and wind velocity. The selection and description of the tree and forest types was a very critical part of the

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model development. For reasons related to practical application of the model, only forest measurements which were easily obtained from photographs or on-site inspection were used as input to the forest characteristic part of the model. The fall velocity and collection efficiency of four drop sizes were used throughout the construct of the model. Wind speeds between 0 and 5 meters per second were used in developing the model while actual field data were used in comparing model predictions to observed data.

Meteorological prediction models were utilized as a modeling framework since these in general are mass continuity expressions that specify the timespace distribution of material which has been released into the atmosphere. Specific application of this model type was used to predict insecticide spray concentration and deposition patterns from known spray physical properties, emission and dissemination factors, meteorological factors, and forest characteristics. The generalized nature of the prediction model is an important feature of the

basic model format and is intended to be universally applicable to all spray problems by simply varying the number and values of the input parameters (Barry, Dumbauld, Cramer 1975).

Twelve trials conducted in the Bitterroot National Forest, MT, by the U.S.F.S. were used as the data base. Zectran, an oil base insecticide, was used in six trials, and the bacterium *Bacillus thuringiensis* (B.t.) suspended in water was used in six trials. Each trial consisted of helicopter spraying, by the swath method, a 40 acre plot. Detailed information on the conduct and results of these trials is contained in a paper (Barry, et al. 1975-b).

Release of liquid insecticide spray from aircraft can be characterized in general by several distinct phases as illustrated in figure 1. In the initial stage of spray release, the droplet spectrum is determined primarily by nozzle configuration and wake turbulence effects. As the material drifts downward toward the canopy, wind drift and evaporation effects take place. Concurrently, the droplets enter

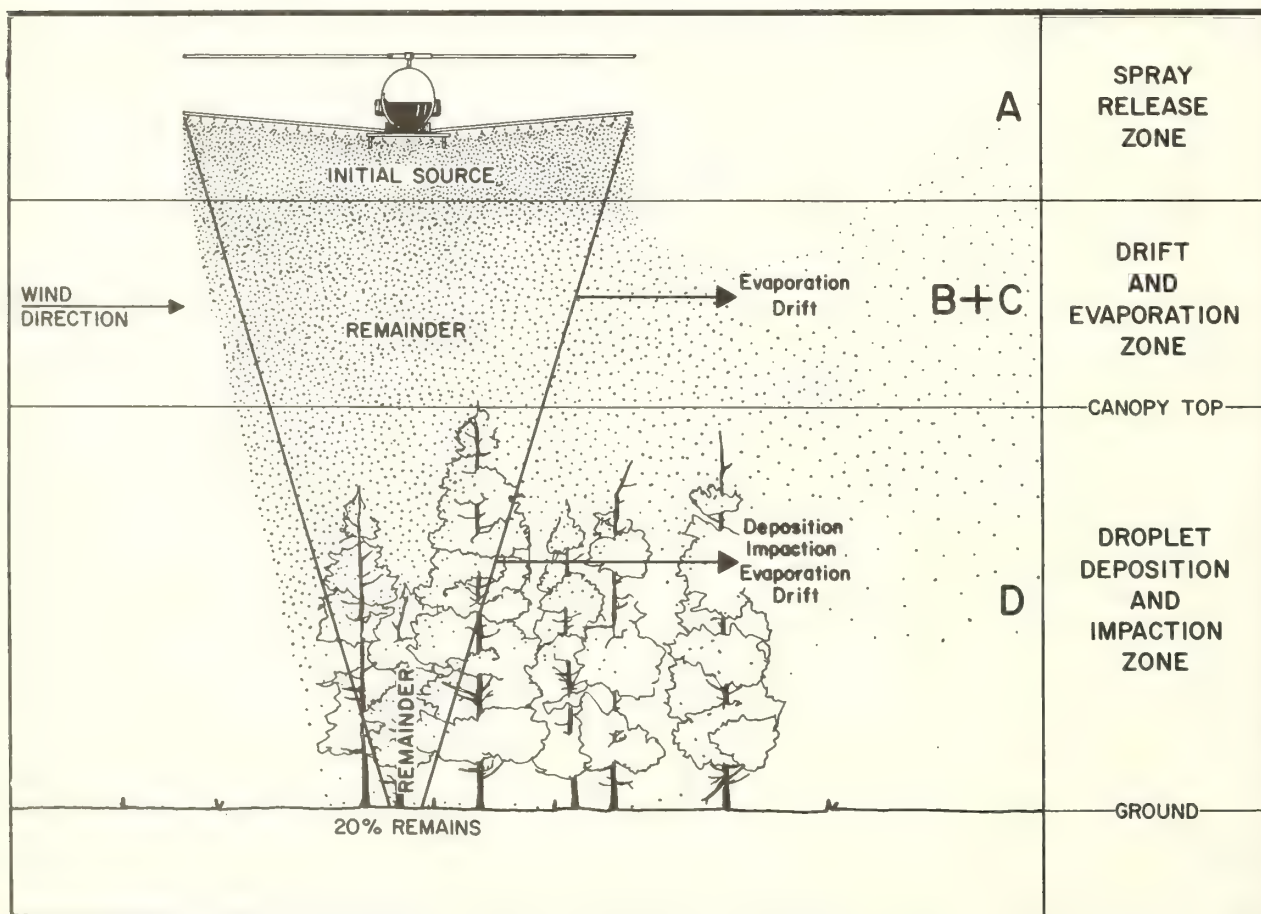


Figure 1.--Physical process involved in insecticide spray release.

the canopy and either deposit or impact on the vegetation or find their way to the ground.

The effects as illustrated in Zones A through C of figure 1 have been modeled successfully for droplets, 50 μm and above, with appreciable fall velocities in open terrain and above forest canopies. There is no known model which predicts the behavior and effects of spray droplets into and within the forest canopy (Zone D).

This study was directed to the scavenging effects of the forest on the spray droplets as they fall through the foliage. Each droplet size was considered to follow a trajectory through the forest to the ground, based upon the droplet's fall velocity and the wind profile in the canopy. This trajectory may or may not intercept a vegetative element depending on the forest, characteristics of tree stand density, foliage density on individual trees, and collection efficiency of various vegetative elements for different sized droplets.

In previous work (Barry, Dumbauld, Cramer 1975) a measure of this scavenging effect was defined as the penetration ratio. It is the ratio of droplets of a given size (diameter) recovered on the ground beneath the canopy to those entering the top of this canopy. Thus, for a given size droplet the penetration ratio is:

$$PR = \frac{\text{Number of droplets recovered below canopy}}{\text{Number of droplets above canopy}}$$

To determine the number of droplets below the canopy, samples are obtained from beneath sample trees throughout the spray block.

The number of droplets at the top of the canopy is determined by measuring recoveries in an open area outside the influence of the forest. It is assumed that the number of droplets which fall directly to the ground is the same which is presented to the top of the canopy. In making these measurements, it is essential that the open area sample represent a recovery which has not been scavenged by the forest. The model proposed in this study computes this ratio for various sized droplets and for various levels in the canopy; that is, the numerator of the above expression is not restricted to ground level, but is computed for 9 levels within the canopy. The model provides a measure of the spatial distribution of mass within the canopy. It is basically independent of the initial spray distribution in the sense that it only provides canopy penetration ratios, not ground distribution patterns as generated by the usual mass transfer models. These penetration ratios could, however, be readily combined with the mass transfer models to provide ground distribution patterns for various droplet sizes beneath the canopy.

The model basically uses the following methodology:

1. Generates a simplified forest
 - a. Specify size and shape of any tree envelope.
 - b. Specify number of stems per acre.
 - c. Specify foliage density type.
 - d. Place trees randomly.
 - e. Specify collection efficiency.
 - f. Specify wind profile.
2. Simulates spray penetration of forest
 - a. Compute trajectory.
 - b. Examine for impact location.
 - c. Tabulate penetration ratios.

Trees are simulated in the model by a tree envelope, which is adjusted to the size and shape of the average tree. Tree shape is determined from photographs or physical measurement of the selected forest. The model is capable of simulating up to three different tree shapes for any single run, thus multi-species of multi-storied canopies can be simulated. The number of trees per acre per species is also determined from forest measurement or aerial photography.

The probability that the trajectory of a particle which passes through a tree envelope will intersect a vegetative element is a function of the foliage density per tree. This probability must vary from a value near 0 for a completely defoliated and very slender tree to near 1 for a very dense foliated tree. Estimation of this value is presently subjective with the establishment of four foliage density categories. Having specified the above parameters, a simulated forest can be generated using a random-number generator to place the trees according to stand density.

The canopy is then divided into four equal height intervals for assigning an average wind velocity within each interval. The wind velocity in each interval is combined with the fall velocity for each particle size of interest to compute the trajectory vector for the particle in the height interval.

With the trajectory for a specified droplet of size determined, the model computes the height above ground where an intersection occurs between the particle and a random tree envelope which lies along the trajectory. If such an intersection occurs, the probability that the particle actually impacts on the vegetation is computed. In order to do this, three factors are taken into account: fall angle of the particle; foliage density; and collection efficiency associated with that size particle.

Assumptions made concerning the above three factors are critical to the overall penetration ratios obtained. The assumptions made in this study are considered to be only a starting point for further investigation. It was assumed that the probability of intersection is a power function where the exponent is the secant of the fall angle. The probability of penetration (PRPEN) which was assigned to the tree envelope was based upon a view in the horizontal, that is, it provides the probability of intersection for a fall angle of 0° to the horizontal. For steeper angles, the path length through the tree is generally longer and the filtering effect on the particles would tend to grow exponentially with path length. However, the path length is limited by the size and shape of the tree.

Collection efficiency as a function of droplet size is another gray area in that the collection efficiency for a specific size droplet is a function of the impaction velocity and the size and shape of the obstacles within its path. Trees present many size and shape elements to a droplet as it penetrates its envelope; consequently, the tree as a whole, possesses a collection efficiency based on the sum of all these small collection efficiencies for each droplet size. Indeed this may vary with fall angle depending on the orientation of the branch structure for various tree species. At this time, it is not feasible to model each of these effects and integrate them into a viable whole.

In the present study, the collection efficiency for individual droplet sizes was used as a fitting parameter to make the model conform to field data. In this way, the overall efficiency of the tree envelopes was established.

In addition to the predictions of the net penetration ratio to droplet size at ground level which was used in the comparison of data and model, the model output also provides percentage of spray droplets depositing above a given level in the canopy as a function of particle size.

For additional details of the model, the reader is referred to a report by Grim and Barry (1975).

RESULTS

A series of 16 computer runs was made with the model to illustrate how variations in each of the input parameters affect the penetration ratio as a function of particle size. Results are reported (Grim, Barry 1975).

It was interesting to note that there tends to be a built-in compensation for windspeed in the sense that an open stand of trees with light foliage would tend to have higher windspeed throughout the canopy, and this in turn causes a less steep trajectory of the droplets, thus giving a higher probability of capture, whereas a dense forest, with low wind speeds within the canopy, lessens the capture probability at all points except the uppermost portion of the canopy. This effect would probably be heightened by increasing the capture efficiency with impaction velocity.

In addition to the predictions of the penetration ratio to particle size, at ground level, the model output also provides percentage of spray droplets depositing above a given level in the canopy as a function of particle size. This is illustrated in figure 2. There is no significant difference in the collection of 50 μm and 100 μm droplets for this set of forest and meteorological parameters, whereas a considerable difference exists for 200 μm and 400 μm droplets.

Another series of 12 model simulations were made to compare model predictions to observed data for spray penetration as a function of drop size. Computer input consisted of actual site parameters and conditions, existing at spray time. The results, which are presented in detail by Grim, Barry (1975) are relatively comparable to the observed data. Figures 3 and 4 are examples of these comparisons, one Zectran trial and one B.t. trial respectively.

CONCLUSIONS

A new mathematical model which uses physical characteristics of the spray, wind speed, and basic forest characteristics as input has been developed to predict spray deposition within the forest as a function of droplet size. The behavior of the model output is relatively consistent with the observed data from a series of 12 field trials. The trials, however, were conducted over a relatively limited range of meteorological conditions and forest types. Data generated by these simulations can be of practical importance to the aerial applicator in deciding upon spray strategy and selecting spray equipment for a given set of atmospheric and biological conditions. The first step in the use of these simulations would be a clear definition of the target. Questions to be answered are type of target (leaf or insect), target size, target location (top of tree, mid-crown, branch, type, etc.). With an understanding of the target, simulations can be used in planning forest spray operations.

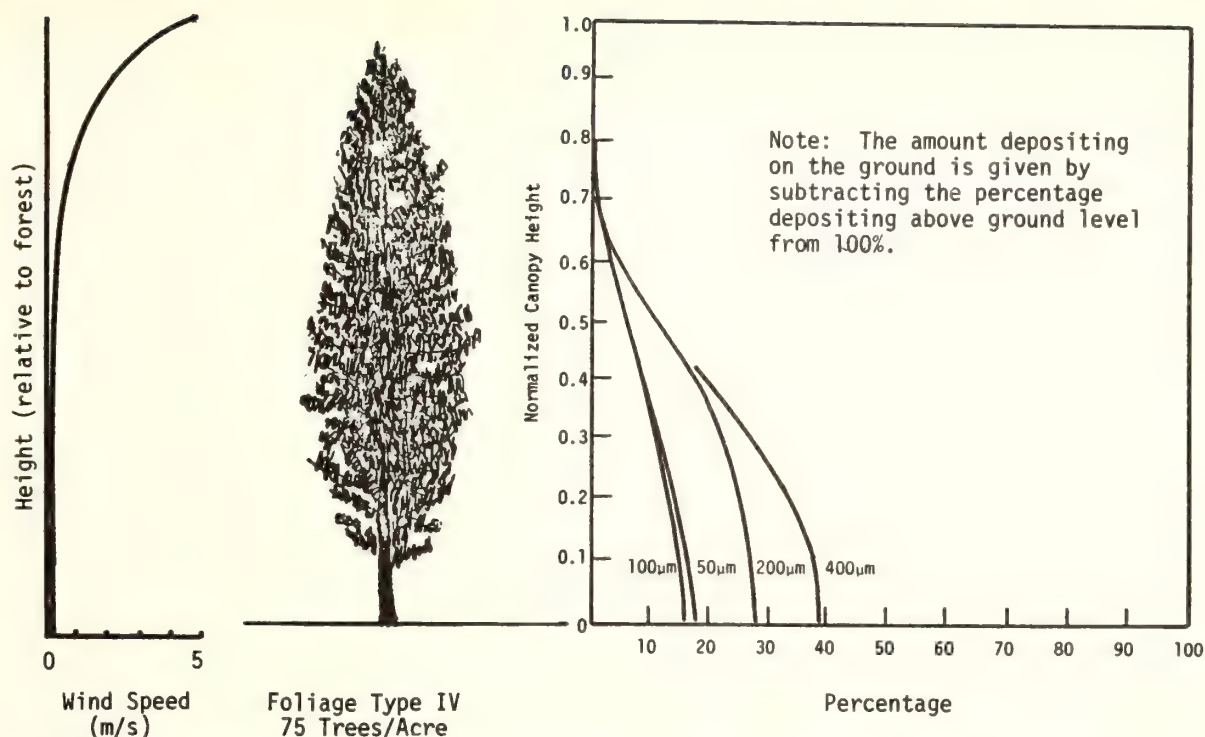


Figure 2.--Percentage of spray depositing above a given level in the canopy for the specified droplet sizes for type IV forest with a density of 75 trees per acre and wind speed of 2 meters per second.

Depending upon the droplet spray distribution and the collection efficiency of the insect, a large portion of the spray mass may, in effect, be wasted by being deposited at the top of the canopy, on the forest floor or lost by drift. The objective, of course, is to make the most effective use of the spray mass by generating droplets which have a high probability of coming in contact and impacting upon the target.

LITERATURE CITED

- Barry, John W., R.K. Dumbauld, and H.E. Cramer.
1975(a). Application of meteorological prediction models to forest spray problems. Document No. DPG-TR-M935P. U.S. Army Dugway Proving Ground, UT.
- Barry, John W., G.L. Sutton, B.S. Grim, R.B. Ekblad, W.M. Ciesla, and J.E. Dewey.
1975(b). Aerial spray evaluation pine butterfly test Bitterroot National Forest, MT. U.S. Army Dugway Proving Ground, UT.

Calder, Kenneth L.

1961. A simple mathematical model for the penetration of forest canopy by aerosols. BL Technical Study 37. U.S. Army Ft. Detrick, MD.

Dumbauld, K.E. and H.E. Cramer.

1973. Model estimates of deposition and concentration for the 1973 field (pilot) test of insecticides on pine butterfly larval population in the Bitterroot National Forest. Prepared by H.E. Cramer Co., Inc. Salt Lake City, UT. Contract No. DAA 09-71-C-0003. Unpublished. U.S. Army Dugway Proving Ground, UT.

Grim, Bruce R., J.W. Barry.

1975. A canopy penetration model for aerially disseminated insecticide spray released above coniferous forests. U.S. Army Dugway Proving Ground, Dugway, UT.

Johnstone, H.F., W.E. Winsche, and L.W. Smith.

1947. The dispersion and deposition of aerosols. Chemical Review. 44:2,353-71.

U.S. Army Dugway Proving Ground.

1971. Model estimates of the dispersion of aerial spray on a forest canopy. Technical note prepared by GCA, Contract No. DAA D09-71-C-003. Unpublished.

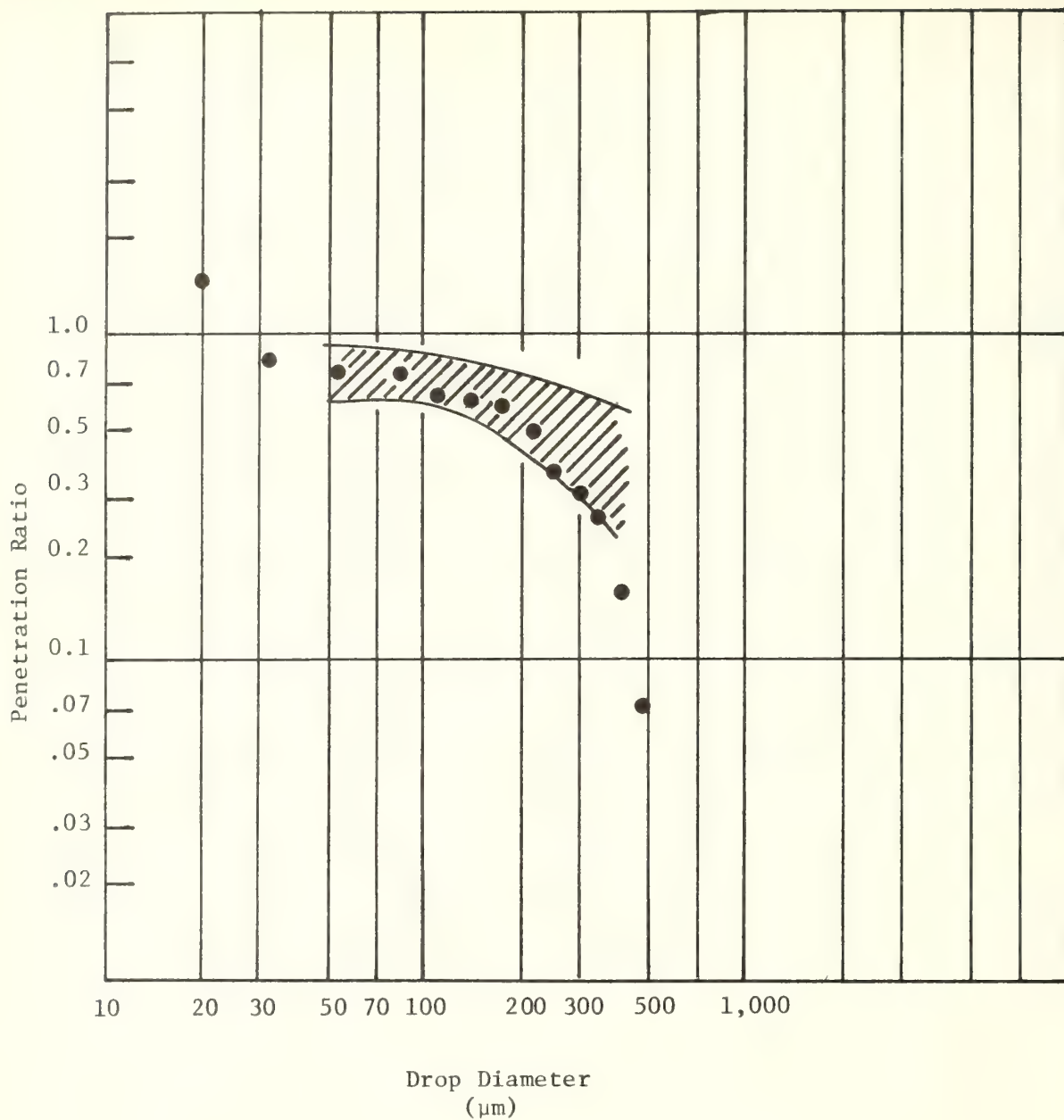


Figure 3.--Zectran trial 3 plot of penetration ratio to drop diameter comparing modeled (cross hatched) to observed (circles) data. Input included wind speed 0.94 m/sec and 50-100 trees per acre.

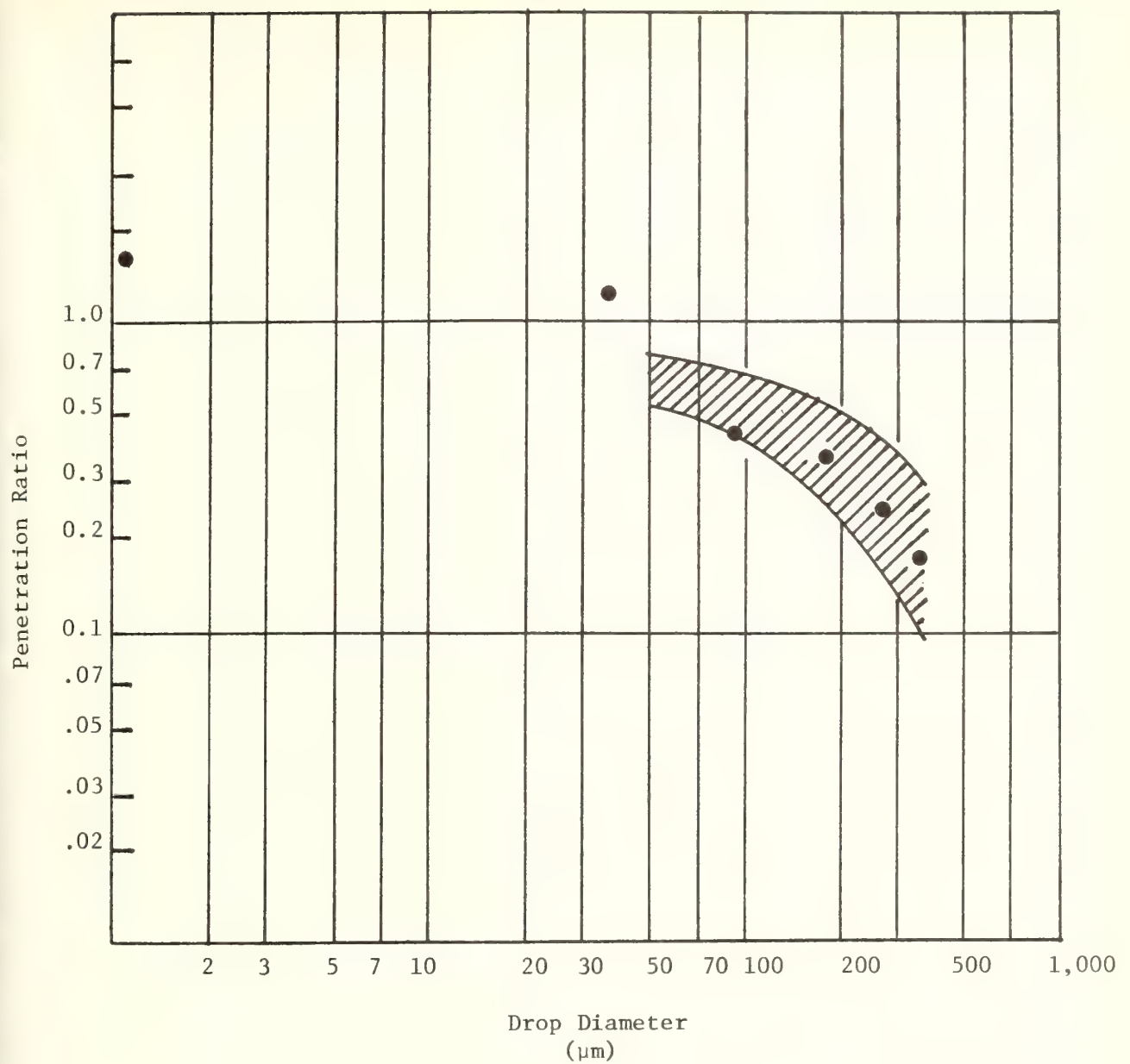


Figure 4.--B.t. trial 4 plot of penetration ratio to drop diameter comparing modeled (cross hatched) to observed (circles) data. Input included windspeed 1.0 m/sec., 25-75 trees per acre in the upper canopy and 175-250 in the lower canopy.

Some Measurements of the Adiabatic Wind Profile Over a Tall and Irregular Forest¹

James D. Bergen²/

Abstract.--Vertical profiles of windspeed were measured over a Douglas-fir stand on a level, exposed mountain site. The stand consisted of scattered old trees left after a harvest ranging up to 30 m in height, and younger trees up to 18 m tall. The average level of maximum foliage concentration was estimated at 14 to 16 m.

Windspeed profiles taken during neutral conditions were used to estimate the aerodynamic roughness length Z_0 and the displacement thickness D , using a least squares fit to the displaced logarithmic velocity profile relation.

The results for three ranges of above-canopy speeds indicate:

- (1) an increase of roughness with speed;
- (2) a general decrease in the displacement thickness with speed; and
- (3) correspondence of the displacement thickness with the level of maximum foliage concentration, for high and moderate speeds.

The ratio of Z_0 at high and moderate speeds for the experimental stand to that found for a shorter, more uniform pine stand is approximately equal to the estimated ratios of the standard deviation of the foliage distribution approximated by a normal distribution above the level of maximum foliage concentration.

INTRODUCTION

When the effect of thermal stratification can be neglected the variation of windspeed with height Z over extensive stretches of tall vegetation has been commonly expressed in terms of the "displaced law of the wall". This relation is generally written as:

$$U = \frac{U_*}{k} \ln \left(\frac{Z - D}{Z_0} \right) \quad (1)$$

where

- $U \equiv$ the local speed at height Z ,
 $D \equiv$ the "displacement thickness",

$Z_0 \equiv$ the "roughness length", and
 $k \equiv$ the von Karman constant
 U_* is usually assumed to be the "friction velocity" defined independently by

$$U_* = (\tau/\rho)^{1/2} \quad (2)$$

where ρ is the local air density, and
 τ is the horizontal shear stress over the vegetative layer.

There is some ambiguity in the literature about the terms displacement thickness or height and the roughness length. Some authors replace D in relation (1) above by $D' - Z_0$ where D' is called the "displacement height"; (e.g. Kung 1961). A less common modification is to replace U by a velocity deficit $U - U_0$. In the first case the relation is unchanged insofar as neither D or D' is independently defined; in the second, if U_0 is assumed proportional to U_* the corresponding term is absorbed in the constant Z_0 which also has no independent definition.

¹/ Paper presented at the Fourth National Conference on Fire and Forest Meteorology, St. Louis, Missouri, Nov. 16-18, 1976.

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There is little theoretical basis for relation (1), and the validity of relation (2) for U_* estimated by the least squares fit of relation (1) to velocity profiles over a forest has never been established. In a wind tunnel simulation of flow over a forest canopy (Kawatani and Sadeh 1971) the value of U_* so inferred was found to be less than half that estimated from direct measurements of the turbulent velocity fluctuations. Although this question (the validity of this estimate of U_*) is obviously critical to the use of the "aerodynamic" method of estimating vertical fluxes over forest canopies, it lies beyond the data to be discussed in this report, which allow no independent estimate of U_* .

Considerable attention has been directed to the questions of how Z_0 and D vary with ambient speed over a given canopy, and how they are related to the physical structure of the forest.

For observations made over pine stands, it appears that Z_0 increases with increasing speed over the canopy, while D decreases although at a much lower rate (Valendik, 1968; Rauner, 1960). However, the degree of the variation differs markedly between stands. Even-aged, uniform stands show little or no systematic variation with speed over a considerable range of speeds (Allen 1968, Bergen 1971, Leonard and Federer 1973, Raynor 1971, Oliver 1971). More irregular stands show a stronger variation (Rauner 1960, Valendik 1968).

The correlation of Z_0 and D with stand characteristics has for the most part amounted to expressing both parameters as fractions of the average tree height -- a parameter which, as shown by Kawatani and Sadeh (1971), should not have any direct relation to either Z_0 or D . What agreement has been found between these ratios for different studies is probably due to a tendency for the experimental stands to be even-aged and in the vicinity of 10 m tall.

For such stands, the observed values for D are very close to the height D_f , for which the maximum amount of foliage can be found; a level for which minimum canopy speeds also occur (Bergen 1971, Kinerson and Fritschen 1971). Such a level may be a level of vanishing vertical shear stress -- an average separation surface for the canopy flow analogous to that produced by corners on objects placed in a normal boundary layer. For a quantitative treatment on the changes in such a level with above-canopy speed, we would need an expression for the local effective viscosity or at least some basis for estimating the vertical divergence of the shear stress at this level. Such expressions are, in general, still to be found. If we may argue by analogy with the separation patterns near corners in the wind tunnel, however, the more clearly defined the canopy foliage maximum the less variation would be expected in D with above-

canopy speed.

If the total effect of the canopy upon the ambient flow may be regarded as the sum of individual shoot wakes, as seems plausible for pine and fir stands (Bergen 1975), the value of Z_0 should depend upon the vertical distribution of such shoots above the level D_f . The normal weight of needles per unit length of shoot is relatively constant for a particular species (Gary 1976) and for individual pine crowns, the distribution of foliage weight along the live crown roughly approximates a Gaussian distribution, with a standard deviation of about 1/5th the total live length (Stephans 1969). For a nonuniform but random canopy the summation of such crowns would also approach a Gaussian distribution, with a standard deviation σ depending upon the rms value of the live crown length weighted by total crown foliage mass. If we may neglect the shear stress at D_f , and if we can assume that the drag coefficients C_B for individual branches are constant over the range of speeds from D to the top of the canopy, then elementary physical reasoning argues that

$$Z_0 = \sigma f(A, C_B) \quad (3)$$

where A is the leaf area index of the stand. The amount of foliage surface per unit length of needle-bearing branch is assumed invariant through the canopy and the same for stands to be compared.

The function $f(A, C_B)$ would be nonlinear only if near-wake interaction were considered, but this is excluded by the hypothesis:

$$Z_0 \propto \sigma A C_B \quad (4)$$

It should be noted that (4) would apply only in the narrow range of U_* where the canopy speeds at all levels above D yield the same value of C_B . Wind-tunnel studies of C_B are not reassuring in this regard. They show a very narrow interval in the 1 to 2 mps range where C_B is essentially constant.

TEST SITE

The measurements to be discussed were made at a relatively level site at 2500 m elevation near Cle Elum, Washington. The forest consisted of an uneven-aged mixture of Douglas-fir and larch, with the former predominating. An edge view is shown in figure (1). The distribution was the result of selective cutting some decades earlier which resulted in a widely scattered group of older trees with heights ranging from 20 to 30 m, and newer growth, more uniformly distributed, with heights up to about 18 m.

In addition to the high variation in tree height, the stand contained many glades several tree heights in diameter.



Figure 1.--The experimental stand, viewed from an edge downwind from the tower site.

The stand floor was extremely rough, with layers of wind-thrown trees and logging slash.

MEASUREMENTS

Gill three-component propeller anemometers were used for the wind profile measurements. They were mounted on 1-m arms clamped to the lattice work of a 37-m crank-up tower (fig. 2). The instruments had a clear fetch for southwest-erly through north and to easterly winds in regard to the tower frame. Wind speeds were measured at 3720, 3540, 3350, 3170, 2900, and 3810 cm above the forest floor.

The same instrument arms supported aspirated and shielded bead thermister thermometers at each level.

Windspeed components were measured at 1-minute intervals together with temperature outputs.

The tower was leveled after instrument placement by means of plumb lines extending from the tower top. Five-minute average vertical velocities at the tower top were less than 5 percent of the total windspeed, which would appear to argue that both tower tilt and local divergence of the flow were slight.

The measurements to be discussed were made from morning to late afternoon on four days. Cloud cover was appreciable for only a few hours of the record.

Anemometer threshold velocity was approximately 25 cm/sec (cm/s).



Figure 2.--The anemometers were arrayed on a 37 m crank-up tower.

STAND SURVEY AND FOLIAGE DISTRIBUTION ESTIMATES

Tree characteristics were sampled by reference to a rectangular grid laid out in the vicinity of the tower. For each of about 20 grid points, the nearest tree was selected for each point of the compass. Trees less than 4 m tall were neglected. In addition, the characteristics of the tallest tree within about 30 m of the grid point were measured.

Foliage characteristics were estimated from diameter at breast height, total height, and the height to the live crown by means of the regression model for Douglas-fir crown structure developed by Kinerson and Fritschen (1971). The estimated distribution of foliage weight for the stand is shown in figure 3. The total leaf area index is about 5, considerably less than for the more uniform stands for which most published wind profile data apply.

The maximum foliage concentration for the stand as a whole is at about 15 m. The dominant trees as a separate group do not show a clear maximum, but highest values apparently are at about 20 m height. When only the newer growth is considered, the maximum foliage is concen-

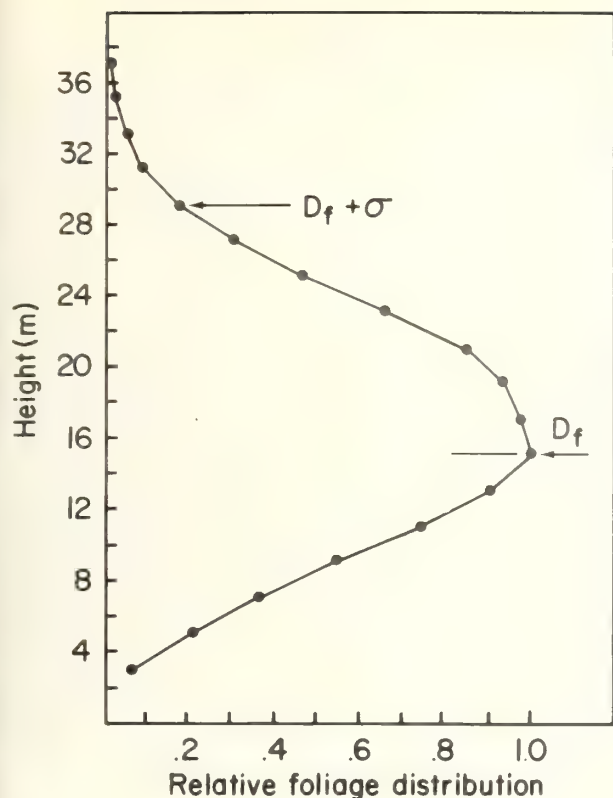


Figure 3.--Average foliage distribution with height for the experimental stand.

trated at 9 m.

The average tree characteristics on the site were: height, 17.1 m with a specific variance of 48 percent; and diameter at breast height (dbh) of 26 cm and 54 percent. Average stem density corresponds to about 256 m² per stem since average spacing between trees as measured between the four trees selected at each sampling point was about 16 m.

ANALYSIS OF DATA

Individual profiles were selected from the record for which the Richardson's number calculated from the windspeeds and temperatures at the top and lowest levels of the profile array were between -0.2 and +0.2. The sample was further stratified by the windspeed at the 38 m level into classes of 200 to 400 cm/s, 400 to 600 cm/s, and above 600 cm/s. These will be referred to as the low, moderate, and high speed categories, respectively.

The speeds for each profile were scaled by the speed at the top of the array and assembled as an average for each of the three

classes. With this scaling, the relation to be fitted was of the form:

$$\frac{U}{U_h} = 1 + B \ln \left(\frac{z - D}{h - D} \right) \quad (5)$$

where (h) is the height of the topmost anemometer (38 m), and where

$$B = \ln^{-1} \left(\frac{h - D}{Z_o} \right)$$

The discussion of the previous section indicates that only positive values of D, h - D, and Z_o are physically plausible. This constraint was incorporated into the least squares fit calculation by introducing the variables (α) and (β) where

$$D = H \sin^2 \alpha + bH$$

$$B = \beta^2 + c$$

The lower bounds for D and B are thus bH and c respectively, while the upper bound for D is (1 - b)H. The scale height H was taken as 28 m, b and c were finally set at 0.5 and 0.05 respectively. The criteria for the choice was that neither D nor B should be at its upper or lower bound at the final values for best least squares fit.

The algorithm used is essentially that published by Hickman (1966) under the program name DATFIT, which was designed for nonlinear curve-fitting problems. It should be noted that the question of the applicability of von Karman's constant in relation (1) above arises solely in the validity of relation (2) for the least squares estimate of U*. In the foregoing procedure the problem is avoided for the determination of Z_o and D.

RESULTS

The number of profiles in the low, moderate, and high speed classes were 35, 40, and 20 respectively. When the curve-fitting procedure described above was applied to the scaled profiles for each of the three classes, the last two fitted relation (7) with the associated constraints relatively well; correlation coefficients were about 0.98. For the first class, however, relation (7) gave a fit not significantly better than a linear variation for positive values of D; the measured wind shear was greatly in excess of that appropriate to relation (7). The profiles in the nearest unstable class at the same speed range, however, gave an acceptable fit to relation (7) with a correlation of 0.98.

The precision of the above-canopy temperature measurements (+ 0.1°C) was marginal given the slight gradients existing over the canopy even with relatively strong insolation. Since

Table 1. Tower-top wind speeds and directions, and temperature drop from 28 to 37 m for speed class profiles

Speed class	Wind speed			Wind direction		Tower temperature drop		
	Average	Maximum	Minimum	Degree from North	Range	Average	Maximum	Minimum
	<i>cm/sec</i>			<i>Degrees</i>		<i>°C</i>		
Low	282	378	216	77	46	-.50	-.06	-.55
Moderate	521	600	405	79	5	+.32	+1.1	-.17
High	771	1000	601	103	11	+.12	+2.3	-.50

the wind speed variation is probably a better index to stability than the measured temperature gradient under low speed conditions, the estimates of Z_0 and D for the low speed class were made from the 13 profiles in the slightly unstable class. Table 1 lists the averages and extremes for tower-top wind speeds and directions, and the temperature drop across the tower array for each of the speed classes.

The values for D for the low, moderate, and high speed classes are 16.8, 14.7, and 16.0 m respectively. The associated roughness heights were 165, 286, and 251 cm. Since errors in the D estimates tend to be associated with errors of the opposite sense in Z_0 , resulting in the relative constancy of $D + Z_0$ noted by Valendik (1968), the observed variation suggests a decrease in D with speed and an increase in Z_0 . We may say with more certainty

that the drag coefficient rises substantially from the lowest speed class to the moderate and high speed classes. It is about the same for the last two classes: approximately 0.14 at 28 m, compared to 0.09 for the low speeds. It would appear that, in the range of constant drag coefficients considered in the argument for relation (4), D corresponds well with the level of maximum foliage concentration for the stand as a whole, 15 to 16 m.

The scaled profiles for each of the speed classes, together with the fitted curves for relation (7), are given in figure 4.

The values of D are of the same order of magnitude -- 16.4 m -- as those calculated by Kung (1961) from Gisborne's measurements over a 24 m tall mixed conifer stand at tree top speeds of about 160 cps, but the estimated roughness length is far smaller -- 250 cm as compared with 1347 cm.

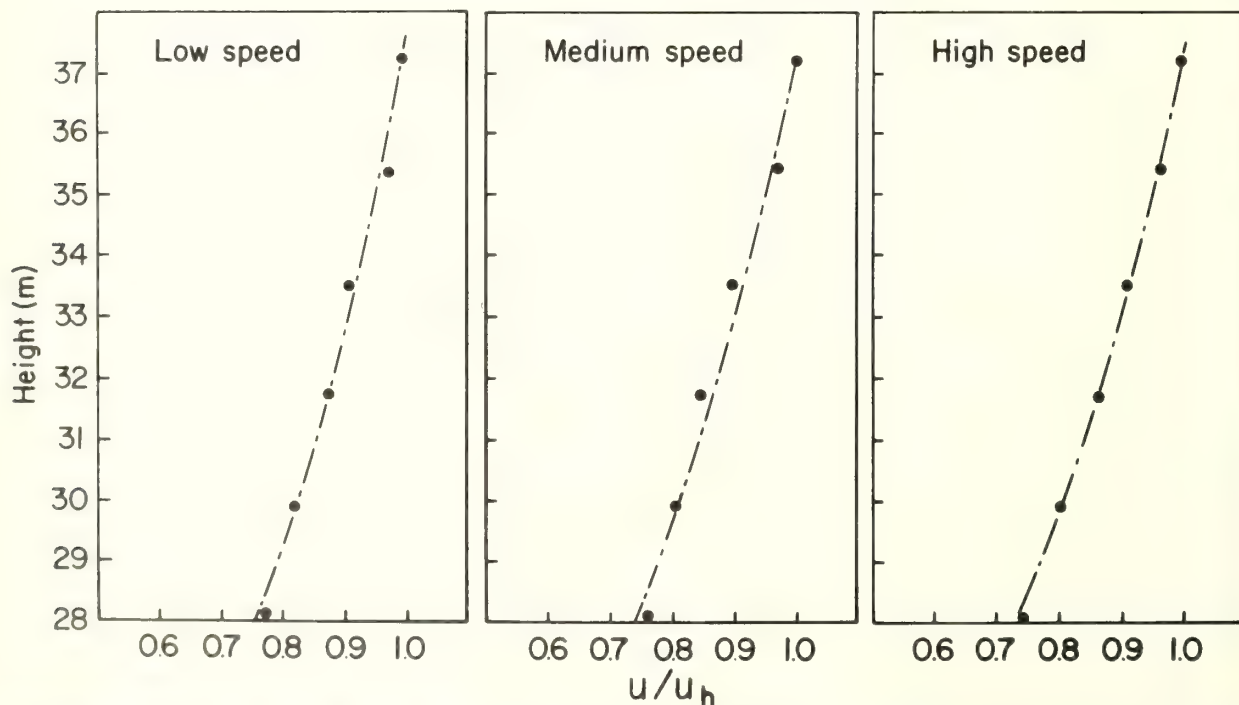


Figure 4.--Scaled wind speed profile, speed groups with estimated displaced logarithmic profiles.

CONCLUSIONS

The results indicate that the close association of D with the foliage maximum observed for more uniform stands is also evident for the heterogenous situation where the foliage maximum is the resultant of many differing individual crowns.

The ratio of D to the average tree height is 0.88, larger than observed for shorter stands (e.g., Oliver 1971). If the maximum tree height is considered, the ratio falls to less than 0.5. The relation of the maximum foliage height to the average tree height is a silvicultural consideration but it would appear that the former is the better predictor for D from forest inventory data.

Relation (4) can be tested in a comparison with results from a more uniform stand (Bergen 1971, 1975). The length (σ) as calculated from the vertical foliage distribution for a 10 m tall even-aged lodgepole pine stand (Gary 1976) is about 200 cm. The leaf area index was approximately 8. The estimated value of Z_0 was 50 cm. With (σ) equal to 1400 cm and leaf area index equal to 5, relation (4) would predict a Z_0 of 220 cm, about 4.3 times the previous value, for the Douglas-fir stand. This is a reasonable approximation, considering the difference in species and thus C_B as well as the errors involved in the foliage estimates for the Douglas-fir stand.

The results seem to indicate that relation (1) may be useful for routine forestry applications involving air flow over forest stands insofar as it may be possible to predict Z_0 and D with reasonable accuracy from inventory data, once the variations of C_B are known in more detail.

REFERENCES

- Allen, L.H.
1968. Turbulence and windspeed spectra within a Japanese Larch plantation. *J. Applied Meteorol.* 7(1):73-78.
- Bergen, J.
1971. Vertical windspeed profiles in a pine stand. *For. Sci.* 17:314-321.
- Bergen, J.
1975. An approximate analysis of the momentum balance for the air flow in a pine stand. In *Heat and Mass Transfer in the Biosphere*; (D.A. deVries and N.H. Afgan, eds.) Scripta; Wash., D.C. 594 p.
- Gary, H.L.
1976. Crown structure and distribution of biomass in a lodgepole pine stand. USDA For. Serv. Res. Pap. RM-165, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Hickman, D.
1966. Applied approximation theory. Tech. Rep. 116. Air Force Weapons Lab. USAF. 102 p.
- Kawatani, T. and W.Z. Sadeh
1971. An investigation of flow over high roughness. Tech. Rep. 11; Project Themis. Fluid Dynamics and Diffusion Lab.; Colo. State Univ. 161 p.
- Kinerson, R.S. and L.J. Fritschen
1971. Modeling a coniferous forest canopy. *Agric. Meteorol.* 8:439-445.
- Kung, E.
1961. Derivation of roughness parameters from wind profile data above tall vegetation. In *Studies of the Three Dimensional Structure of the Planetary Boundary Layer*. Dept. Meteorol., Univ. Wis., Madison, Wis., p. 27-35.
- Leonard, R.E. and A. Federer
1973. Estimated and measured roughness parameters for a pine forest. *J. Applied Meteorol.* 12(2):302-307.
- Oliver, H.R.
1971. Wind profiles in and above a forest canopy. *Q. J. Roy. Meteorol. Soc.* 97(414): 548-553.
- Rauner, Yu L.
1960. The heat balance of forests. [Izvestia Akademii Nauk SSSR: Seriya Geograficheskaya No. (1) p. 49-59]. OTS. Transl. IPSI Cat. No. 1342-TT 65-50033, p. 1-12.
- Raynor, G.S.
1971. Wind and temperature structure in a coniferous forest and a contiguous field. *For. Sci.* (17):351-363.
- Stephans, G.R.
1969. Productivity of red pine (I): Foliage distribution in tree crown and stand canopy. *Agric. Meteorol.* 6(4):275-282.
- Valendik, E.N.
1968. Veter i Lesnoj Pozhar [Weather and forest fires]. Akademiia Nauk SSSR Sibirskoe Otdelenie Institute Lesa i Dreveseny: Moscow, Izdatvo Nauka. 117 p.

First Results on a Differential Interception Method of Estimating Canopy Dosage from Aerial Pesticide Applications¹

James D. Bergen and Richard A. Waite^{2/}

Abstract.--Current methods for assessing aerial pesticide applications do not allow an estimate of the actual pesticide dosage as predicted by available models for spray penetration into the forest canopy, or provide the information required to estimate deposition on the various foliage elements. Field experiments are reported on spray deposit measurements using cylinder pairs exposed in a forest canopy. The relative deposition of droplets in 8 to 52 μ size range on a 2.5-cm cylinder and a 6-cm cylinder is used to estimate the effective ventilation speed for the cylinder deposits, which may then be used to estimate the corresponding dosage for droplets in that size range.

The nonuniformity of the deposit requires intensive sampling. The effect of local turbulence is evident in the deviation of the deposit pattern over the cylinders from that predicted from theoretical considerations.

INTRODUCTION

Although aerial spraying of pesticides into forest canopies has become commonplace, increased awareness of the hazards involved requires that we minimize the undesirable side effects of massive applications of such agents. As a result, there is a need for greater precision in the assessment and design of forest spray operations. While the conventional ground-deposit-card method of estimating the total amount of material applied to the foliage works well for large droplet sizes, it fails to account for that portion of the material in droplets below 100 μ in diameter, and gives little information on the vertical distribution of the spray deposit within the canopy.

While direct measurement of foliage deposition would give the best estimate of the

deposit distribution as well as an indication of the drift loss, in practice this is a difficult and time-consuming procedure. The obvious alternative is to correlate deposition measurements on cards placed in one way or another near or in the foliage with deposition on the foliage surfaces. This correlation should be a function of three parameters: the drag coefficient of the foliage element, the local windspeed during the passage of the spray droplets, and the time (t) integral of the volume concentration (n) of droplets of a given size during the spray application, termed the "dosage", (N):

$$N = \int_0^{\infty} n dt$$

The lateral drift of small droplets would be directly expressed as the product of the dosage and the average windspeed.

As a matter of convenience, deposition cards mounted on cylindrical forms of various sizes have been routinely used for such measurements.

The ability of cylinders to intercept horizontally moving droplets of a particular diameter (d), and density (ρ) at a given,

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steady windspeed (U) is formally expressed as the "collection efficiency" (E). The efficiency is defined as the ratio of the number of droplets impacted on the cylinder (C_I) to the number of droplets contained in the volume of the aerosol cloud swept by the cylinder:

$$C_I = E U N D L \quad (1)$$

where (D) is the cylinder diameter, and (L) its length.

Values of (E) have been calculated for particular droplet-cylinder combinations by a number of authors (Langmuir and Blodgett 1943, Lundberg and Chilton 1962) and have been widely used in such problems as wire icing estimates and filter design. These calculations show reasonable agreements with small droplets ($d < 100 \mu$) in wind-tunnel situations, but do involve some critical assumptions relevant to more complex ambient air flows:

- (1) The droplets are assumed to be moving at the local airspeed up wind from the cylinder, an improbable situation for a spray droplet larger than about 100μ falling through a typical boundary layer flow.
- (2) The air flow is assumed to be steady, a condition rarely found in natural boundary layers.
- (3) The air flow is assumed to be perpendicular to the cylinder axis.

Given these assumptions, (E) may be shown to depend upon two dimensionless numbers, (K) the "inertial parameter" defined as

$$K = \frac{1}{9\mu} \frac{d^2 U \rho}{D} \quad (2)$$

and a parameter (ϕ) where

$$\phi = 9 \frac{\rho_a^2 D U}{\mu \rho} \quad (3)$$

where ρ_a and μ are the density and viscosity of the air.

The speed (U) which enters into definitions (2) and (3) is the magnitude of the wind component normal to the cylinder axis. The function $E = f(\phi, K)$ to be used in the following discussion is that calculated by Langmuir and Blodgett (1943) and presented as a convenient nomograph in the Air Weather Service Climatic Methods File (U.S. Air Force 1960). The velocity field for these calculations corresponds to potential flow around the cylinder.

The deposition to be expected without impaction -- that is, in still air -- (C_S) is

$$C_S = V_T N D L \quad (4)$$

where (V_T) is the terminal velocity of the droplets, about 1.9 and 6 cm/sec for 24μ and 41μ diameter droplets, respectively.

Strictly speaking, (C_S) and (C_I) may not be superimposed. The response of droplets to the local air motion depends upon their total speed relative to the surrounding air for droplets larger than a few microns. A falling droplet would act as a droplet of lower mass in regard to its impaction on a local surface. The available calculations do not consider the coupling of the sedimentation velocity and the horizontal motions, and for the following discussion this effect will be assumed negligible. With this assumption the total deposition or catch (C_T) on the cylinder may be written

$$C_T = N D L (E U + V_T) \quad (5)$$

The deposition density (c), is equal to (C_T/DLN). Some calculated values of c for oil droplets of diameters 24μ and 41μ are given in fig. 1. The calculations are made for two cylinder diameters, 6.5 and 1.25 cm, labeled (L) and (S) respectively, and plotted against the ventilation speed (U). Ambient conditions of 25°C and sea level pressure are assumed.

At speeds below 20 cm/sec the deposition is dominated by sedimentation.

Where (U) is known, the measured depositions of droplets as measured around sample chord strips of the cylinder card could be used via relation (5) and the curves of fig. 1 to calculate (N) for 24μ or 41μ droplets.

Accurate measurement of the local wind speed is not practical within the forest canopy. Both wind direction and speed are random functions of position and time. The measurements described in this paper are part of an exploratory effort to determine the local effective windspeed (U) in such a situation by the use of cylinder pairs.

If we consider the two cylinders close enough as to experience no systematic difference in local values of (N) at a particular time, we may define a relative catch density deficit (RCD) by

$$\text{RCD} = \frac{c_a - c_b}{c_a + c_b} \quad (5)$$

where the subscript (a) denotes the smaller cylinder and (b) the larger.

By substitution:

$$\text{RCD} = \frac{(E_a - E_b) U}{(E_a U + E_b U + 2V_T)}$$

and the RCD for a particular droplet size will depend only on the local speed.

The variation of RCD with (U) is shown in fig. 2 for the two droplet and cylinder sizes considered above. These values will be taken as representative of droplets in the 8 to 30μ range and the 30 to 52μ range in the discussion below.

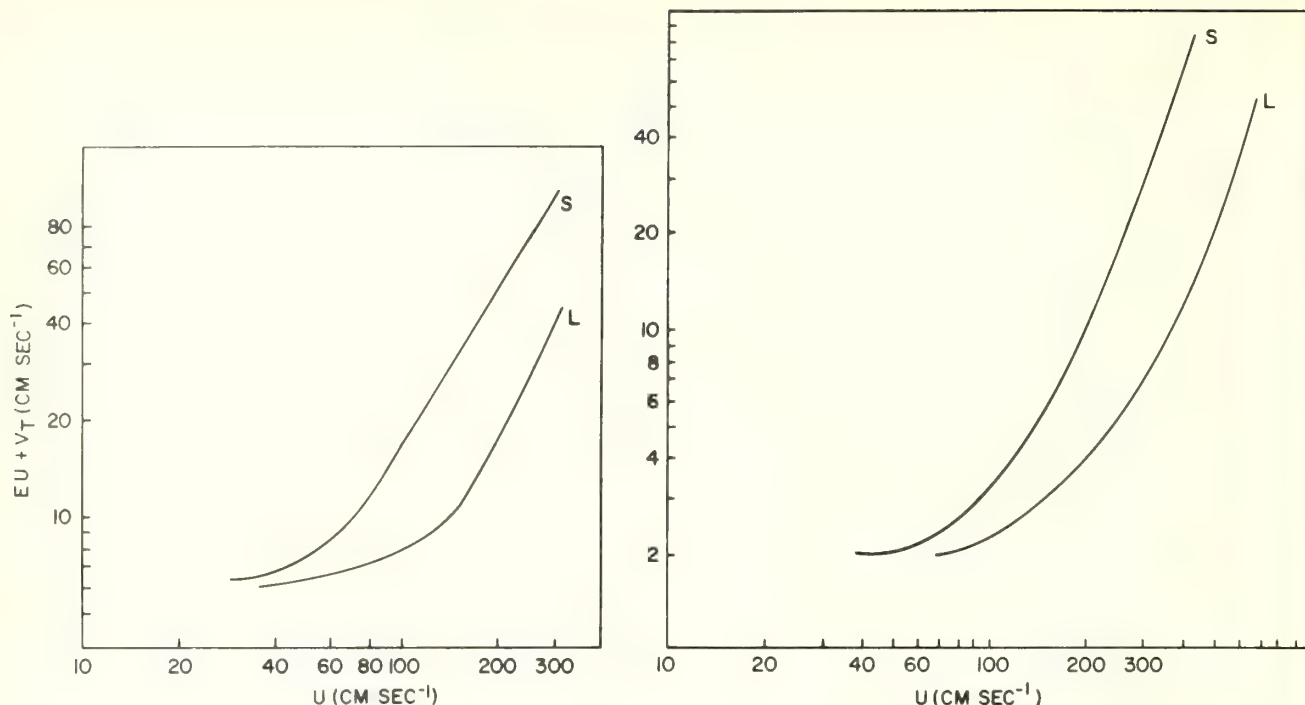


Figure 1.--Variation of deposition velocity with ventilation speed for (A) 41 μ diameter oil droplets, and (B) 24 μ diameter oil droplets. L = large cylinder, S = small cylinder.

Since canopy windspeeds are generally in the range from 50 to 200 cm/sec during aerial spray applications, the curves of fig. 2 suggest a means of estimating the local ventilation speed from the relative catches on such cylinders in the 41 and 24 μ droplet diameter ranges.

A typical measurement (as noted below) resulted in a stain droplet density of 11.3 cm^{-2} on the small cylinder and 3.7 cm^{-2} on the large cylinder, for stain diameters corresponding to the 24 μ droplet range. The corresponding densities for the 41 μ range were 8.2 and 1.5 cm^{-2} respectively. The calculated RCD for the smaller droplets was thus about 0.5, a value which could be by the curve of fig. 2 occur with speeds of 240 or 700 cm/sec. The corresponding RCD's in the 41 μ range would be 0.65 or less than 0.1 as compared to the calculated value of about 0.7. Our estimated speed is thus about 240 cm/sec. If we turn to the deposition velocity ($EU + V_T$) curve of fig. 1 we find a value of 18 cm sec^{-1} for the small cylinder and 5.3 cm sec^{-1} for the large cylinder. Returning to the measured stain densities and applying equation (5) we find estimated dosages in the 24 μ range of 0.63 and 0.7 droplet cm^{-3} for the small and large cylinder separately with a mean of about 0.66 droplet cm^{-3} . The same calculation may be carried out for the 41 μ droplets.

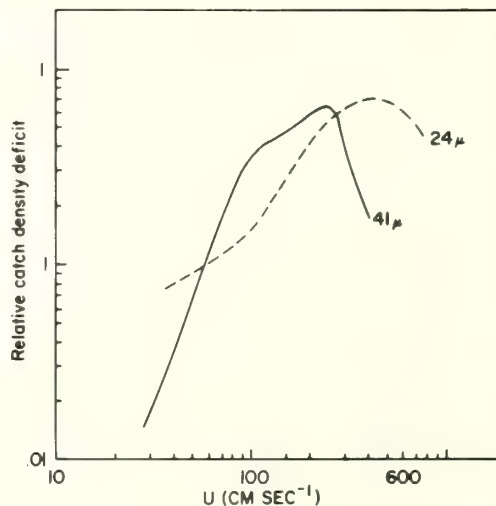


Figure 2.--Variation of RCD with ventilation speed for two droplet sizes.

IMPACTER DESIGN

Unit cost is a critical factor in determining the density of sampling in spray assessments. The ready availability of empty beer cans at a nominal cost as well as their light weight suggested their selection for one of the cylinder sizes. The use of styrofoam dowel for the smaller cylinder eliminated the need for relatively expensive cutting and drilling required for wooden dowels.

Figure 3 is a schematic of the impacter design used, with the two cylinders mounted coaxially and horizontally on a standard wire coat hanger.

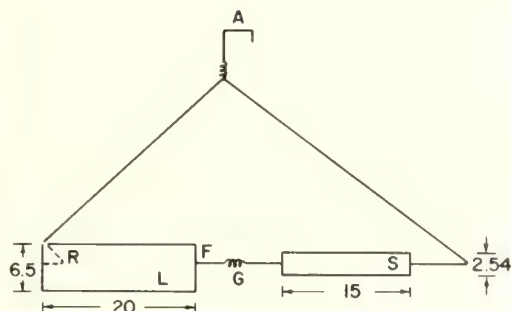


Figure 3.--Schematic of deposition cylinder pair. Beer can (L) is held in position by the bent corner of the coat hanger inserted in tab opening at (R). Wire is reconnected at (G). Frame is held to a line by a spring paper clip at (A). Styrofoam cylinder (S) is impaled on lower coat hanger bar. All measurements are given in centimeters.

In the field situation to be discussed, the coat hanger top (A) was clamped to a taut nylon line suspended from a pulley hung between trees. Khrome coat cards were fastened completely around the normal circumference (the chord) of the cylinders with rubber bands.

A horizontal cylinder arrangement, rather than vertical as suggested by Reid (1965), allowed the total deposition -- including the larger drops which show negligible horizontal motions at low windspeeds -- to be measured with the same deposition cards. The horizontal arrangement also simplified the sampling problems involved in estimating the catch. If the air flow is primarily horizontal, the maximum impaction deposition remains at the cylinder midline, even for multiple depositions made with reasonable variations in horizontal wind directions. The midline density therefore reflects the average speed and concentration

as distinguished from the multiple discrete maxima that would be observed with vertical cylinders in the same situation.

SAMPLING

The collection efficiencies on which the curves of fig. 1 are based refer to the entire chord of the cylinder, and strictly speaking provide only estimates of total chord accumulations or average stain densities.

The safest procedure would be to survey the entire chord as suggested by Reid (1965), but this is time consuming and expensive, even using electronic scanners such as the Quantimat 3. It would therefore be of advantage to develop a sampling system that would allow a quicker estimate of total chord concentration.

The total accumulation of droplets on the cylinder chord consists of two contributions: (C_i) the impact deposit, and (C_s) the sedimentation deposit. Their variation over the chord should be quite different.

By geometrical consideration, (C_s) should vary as $(\sin \gamma)$ over the upper chord where (γ) is the angle from the horizontal and thus, approximately, from the midline stain maximum if such can be determined. On the lower chord (C_s) should be uniformly zero. There should be no effect of either windspeed, droplet size, or cylinder size on the (C_s) distribution.

The (C_i) deposit by contrast is, for steady flow, confined to the section of chord between $(+\gamma_m)$ and $(-\gamma_m)$ where (γ_m) is termed the "critical angle" (Lundberg and Chilton 1962). The angle (γ_m) depends on (ϕ) and (K) above; it increases sharply with the latter. At a speed of 90 cm sec^{-1} , γ_m for the 41μ droplets on the large cylinder is about 0.2 radian; for the small cylinder it would be 0.4 radian. At 180 cm sec^{-1} , γ_m for the cylinders increases to 0.25 radian and 0.8 radian, respectively. For the 24μ droplets the variations are smaller but in the same sense.

Since devices such as the Quantimat are used with a fixed sample area, the midline sample would include a larger fraction of the impacted droplets at lower speeds and for the larger cylinders.

Since the (C_s) distribution does not vary with speed, the midline sample should contain a (C_s) deposit equal to a constant fraction of the deposition on the top of the cylinder.

From these considerations we would expect a double maximum pattern on a cylinder exposed to a reasonably steady flow; the magnitude of the midline maximum relative to the maximum at the top of the cylinder would increase with speed and be greater for the larger cylinder at the same speed. However if the scanning devices use a fixed sample area, the fraction of the impacted droplets included in this area would be larger for lower speeds and the larger cylinder.

For an upstream flow with considerable turbulence or for the net deposit caused by multiple cloud passages with differing speeds and/or directions, one would expect the inertial deposit to extend well beyond (γ_m) estimated from the speed (U) implied by the ratio of deposits at the midline.

MEASURED DISTRIBUTIONS

Sixteen cylinder pairs were exposed in a forest canopy during an aerial spray operation. They were hung within the canopy, as described above, at heights ranging from 4 to 25 m and at distances of 30 to 90 m downwind from the helicopter flight path. The application consisted of seven swaths laid down over the same path over a period of about 20 minutes.

Details on the canopy characteristics can be found in an earlier report (Bergen 1976). The spray consisted of Rhodium B dye in a diesel oil carrier. The experiment was carried out in the early morning, with above-canopy windspeeds varying from 150 to 250 cm/sec as measured by 5-minute averages at about 20 m over the tree tops.

The deposition cards were analyzed on Quantimat equipment using experimentally determined spread factors. Sampling areas for the scan were 0.98 cm^2 . The cards were scanned at 1 or 2 cm intervals along the chord. Only cards with a midline deposit density of at least 6 drops per cm^2 were surveyed (15 cards). Chords were scanned at three locations along the cylinder axis.

The results for drops in the 24μ and 41μ ranges are shown in figures 4 and 5 as polar plots of droplet density expressed as a fraction of the average droplet density over the cylinder plotted against the angle from the apparent midline position as indicated by the deposition maximum. The plots are divided into high and low speed insofar as the 24μ RCD for the pair indicated ventilation speeds less than or greater than 160 cm/sec.

Perhaps the most apparent feature of the plots, particularly for the more detailed beer can results, is the extreme irregularity of the deposits away from the very clear midline maximum. There is considerable deposition at the lee midline, where, for steady flow by the Langmuir-Blodgett model, there should be none -- a consequence presumably of either turbulent fluctuations in wind direction during droplet impingement, or of reverse flow in the cylinder wake. The beer can results show, as would be expected from the previous discussion, the two maxima for the independent distributions (C_s) and (C_l), with the former most prominent for the low speed data. For the higher speeds, the (C_s) maximum is submerged in the more widely distributed (C_l) pattern. The results for the

small cylinder are more ambiguous, perhaps because of the lower angular resolution provided by the scan sample area. The relative decrease in (C_s) is obvious for the smaller drops, but less apparent for the 41μ drops. For both speed classes the lee midline deposition is appreciable.

It appears the impaction deposit on the cylinders occurred to an appreciable extent with nonhorizontal winds, a conclusion that would cast considerable doubt on any simple sampling procedure using less than 5 points on the chord. Still, insofar as the turbulence characteristics of natural conifer stands resemble each other, an estimate of total deposit from midline samples does not appear to be entirely out of the question for the 24 and 41μ droplets. The ratio of the midline deposit to total deposit varies little for the droplets -- about 15% and 14% for the small and large droplets on the beer can, and about 29% and 25% on the small cylinder. These ratios are particular, of course to the sampling area, the type of turbulence, and droplet size. These estimates would probably be of some validity in approximate estimates for cylinder pairs deployed in similar stands.

SIGNIFICANCE OF THE SPEED

The relation of (U) to the time average wind as generally defined with conventional measurements is not obvious. Physically we should expect (U) to approximate the rms value of the windspeed during the relatively short periods of time during which the spray cloud or clouds pass the collector. For a large enough number of swaths this rms value may approach that estimate from the usual 5-minute average; this in turn is generally defined in terms of the gust factor or turbulence intensity, the ratio of the standard deviation of the velocity to its average. For forest canopies turbulence intensities of 2 or 3 are not uncommon at lower speeds, so that (U) may exceed the mean speed by a factor of 3 or 4. Balancing this effect to some extent is the random orientation of the collector relative to the local wind direction; the average of a large number of such local estimates would be less than the true speed by a factor of 0.7.

In the sample calculation made above: if the cylinder were at right angles to the average wind direction a reasonable measure of the lateral drift would be the product of the estimated mean velocity which is about 80 cm/sec times the dosage, i.e. about $40 \text{ droplets cm}^{-2}$.

The correlation between the local dosage and wind speed and the final deposition on a typical foliage element has yet to be established. Calculations such as those carried out for solid, smooth cylinders to establish (E) have not

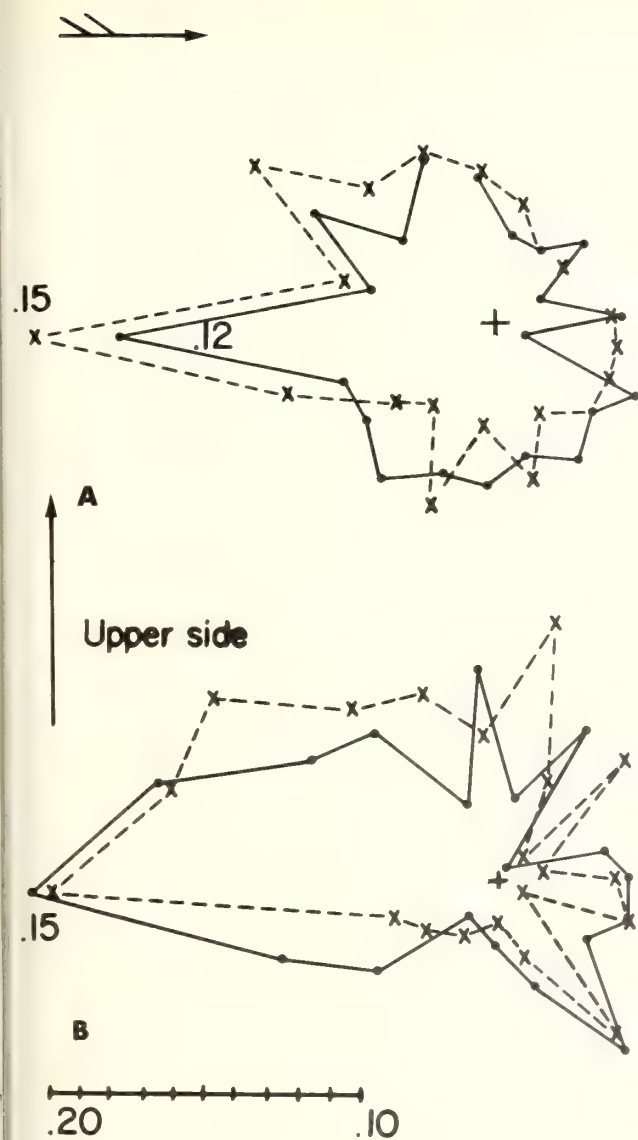


Figure 4.--Composite angular distribution of droplet stain density normalized to total catch. (A) Large cylinder at low speeds (130-160 cps); (B) Large cylinder at high speeds (160-240 cps). Scale represents magnitude of normalized stain density, + indicates center of cylinder, x = 41 μ, ● = 24 μ.

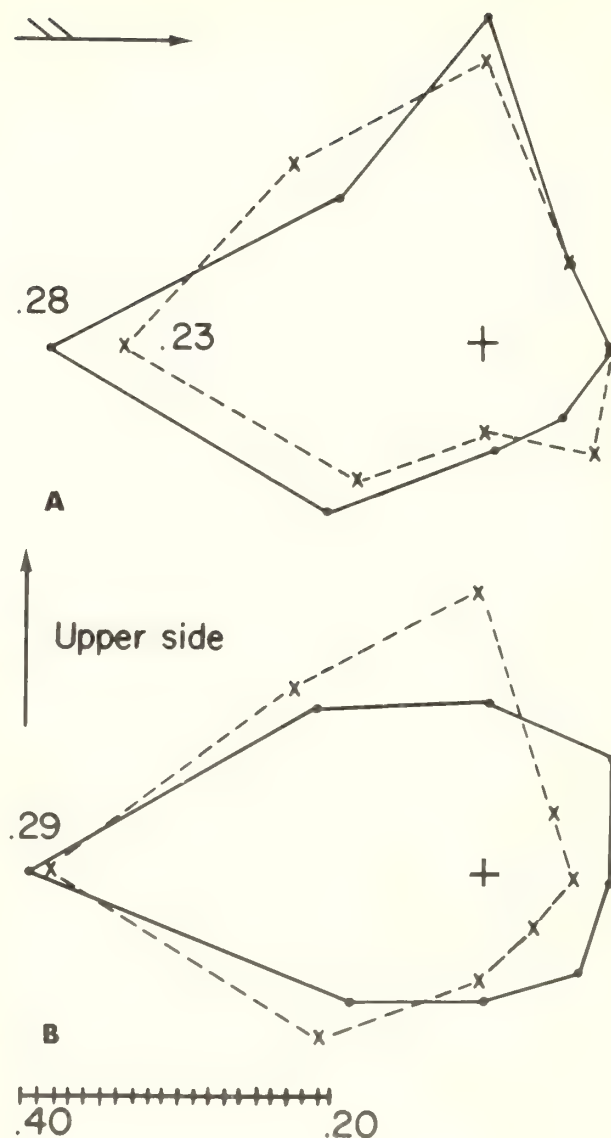


Figure 5.--Composite angular distribution of droplet stain density normalized to total catch. (A) Small cylinder at low speeds (130-160 cps); (B) Small cylinder at high speeds (160-240 cps). Scale represents magnitude of normalized stain density, + indicates center of cylinder, x = 41 μ, ● = 24 μ.

been made for rough, porous bodies suspended in an air stream. Any available data on interception by branches or crowns refer to fog droplets with sizes in the $1\ \mu$ range. For such particles (Yosida and Kuraiwa 1953) the total interception appears to vary directly with (N), the total projected leaf area, and $(U^{3/2})$. It seems obvious that further study on this point is called for.

CONCLUSIONS

The double cylinder method appears to offer a practical way of measuring dosage and estimating lateral drift in a forest canopy in forest spray operations. The observed deposition patterns also indicate that the total cylinder deposition, and thus the local ventilation airspeed, may be reasonably estimated from the cylinder midline densities. For the beer can the midline-to-total ratio is about 0.15 for droplets in the $8\ \mu$ to $52\ \mu$ range. For the small cylinder, the appropriate factor is about 0.27.

REFERENCES

- Bergen, J.D.
1976. The adiabatic windspeed profile over a tall and irregular forest. (this symposium)
- Langmuir, I. and K.B. Blodgett
1945. Report R. L. 225. General Electric Laboratory, Schenectady, N.Y.
- Lundberg, R.E. and E.G. Chilton
1962. Drag of cylinders and spheres in steady particle-laden gas flow. Tech. Report (Pt. 2) DASA-1296. Stanford Research Institute. 47 p.
- Reid, E.B.
1965. Aerosol cloud sampling using impingement collectors. Summary Report 65-4, 23 p. Chemical Division, Dugway Proving Grounds, U.S. Army
- U.S. Air Force
1960. Estimation of ice accumulation on wires and radomes. Climatic Methods File: Chap. 10, Air Weather Service, U.S.A.F., Wash., D.C.
- Yosida, Z. and D. Kuriowa
1953. Wind force on a tree and the fog water thereby captured. In: Studies on Fogs. T. Hori, ed. Tanne Trading Co, Japan 399 p.

Session V
(Panel Discussion)
Weather Service Needs, Capabilities and Policies

Chairman: John Bethea

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Weather Service Needs in Planning¹

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From my perspective as an administrator in the Forest Service the needs of the Weather Service are quite simple and straight forward - whatever it takes (methods, procedures, techniques, etc.) to provide land managers data and information to identify effects of proposed land management decisions on air and air quality, and to provide weather information as it may relate to land capabilities and management configurations.

In the context of the land planning process there is a manager at each level of our hierarchical organization, the Regional Forester at the Area Guide level, the Forest Supervisor at the Land Use Plan level, and the District Ranger at the project level. Each has decisions to make relative to the use of the land under his jurisdiction.

Meeting the needs of land managers received more emphasis recently with the passing of the National Forest Management Act of 1976. This Act will require an intensive and detailed land use planning effort on the National Forests over a relatively short period of time. To pull this off successfully, land managers are going to need precise data readily available to them, and proven analysis processes so that the answers they come up with are sound and defensible.

The Weather Service, or weather information, comes to bear in many facets of National Forest land use and project planning. I want to concentrate my discussion on land managers needs in two areas: Air quality and winter sports.

Air quality information for land use planning is needed at all planning levels from Area Guides to project planning.

As I said before, the same information is needed at each level, however, the closer to the ground the greater the need for more precise data.

In general, the information needed is:

1. Susceptibility of an area to air pollution from each pollutant - i.e.

how much emission of a given pollutant can an area receive before the EPA air quality standard for that pollutant is exceeded. In other words, how big is the bucket?

2. What is the current air quality relative to each pollutant? Or how much of the bucket is already filled with pollutants and how much more matter can the area take before it exceeds the EPA air quality standard for that pollutant?
3. What are the expected emissions associated with each land use alternative or, will the alternative cause the bucket to runneth over, and if so, by how much?

The input data needed to arrive at this air quality information must generally come from existing data because we cannot wait one or two, or three years while it is put together - It's needed now.

The process for gathering data must be straight forward, easily understood and readily available to Forests and Districts so that it can be plugged into the plan. I cannot over-emphasize this point enough. These boys at the Forest and District are going flat out and when they need some answers they need to be able to go to the machine and get it right back. The process cannot be something that it takes a Ph.D. to understand or a computer specialist to operate. In the "Technology Transfer" as it's called these days, it has to be taken out of the technical jargon and explained in language that the manager can understand and follow. It isn't a matter of having the smarts to figure it out - he just doesn't have the time to figure it out and so it won't be used. "For the want of a nail..." and so on.

And now the good news. The Mountain Meteorology Group at Rocky Mountain Forest and Range Experiment Station is developing and proving out a process to get at these very questions and processes. What I have seen of the information produced in Colorado on a State-wide basis, and for the Greater Yellowstone Cooperative Regional Transportation Study, it provides precise enough information for land use planning at the Area Guide and Forest land use planning level.

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But we cannot stop here. As the planning effort steps down to the project level, the level of detail increases and the location as to where developments or activities are to take place becomes more specific. The level of detail relative to air quality information must be stepped down accordingly.

At the Area Guide and Forest level, we are dealing with map scales of 1:500,000 or 1:250,000. At the District level, however, map scales are generally at 1 or 2 inches per mile. The process must be able to accept the same kind of input data at these more precise scales and provide output data and information adequate for use at these scales.

Land managers need a process that can be quickly and easily stepped down from one planning level to another.

Environmental Protection Agency standards are based on the "normal worst" atmospheric conditions that are likely to occur in the area. These conditions such as wind speed, temperature, barometric pressure, etc. can be defined. But land managers need to also know the probability of occurrence. Can he expect these conditions 10% of the time? Or 50%? Or once a year?

Closely associated with air quality - particularly particulates - is visual management in the National Forests. It deals with the visual harmony among all parts of the landscape - landforms, vegetation, structures, water and air. The Forest Service objective of landscape management is to manage all National Forest System lands as to attain the highest possible visual quality commensurate with other appropriate public uses and benefits.

So the land manager needs Weather Service data and processes not only to work within EPA standards but to "attain the highest possible visual quality."

Emissions from certain activities or uses may be within established EPA standards but still result in degradation of the visual quality. At what point do suspended particulates become visible and adversely impact the view of the landscape? Under what conditions will emissions from a particular use or activity reach that point? How will particulates drift from their source and what will be their concentrations? Methods and procedures for the land manager to answer these and similar questions must be readily available to him.

Potential Winter Sports sites is another area where help is needed. Take for instance a potential site where the aspect appears right, the elevation appears right, the slopes and terrain appear right. But what of the wind speeds and patterns and what about the pattern of snow deposition? Can the State-wide data be brought down and identify these factors on a 10,000 acre area with a sufficient degree of reliability?

Can known weather data on one area be extrapolated to a nearby area and what are the key components that must be known in order to make the extrapolation?

How can we get an adequate weather picture on a potential Winter Sports site without having to install and maintain weather equipment in the area for a number of years or, what is the minimum data base needed on a new area in order to make a reliable extrapolation?

I have talked of two areas where land managers need help to adequately redeem their land use planning responsibilities. Some processes and procedures are already developed. With some I think the technology is there, but as indicated by the questions I have asked, the process needs further development and the job of figuring out how still needs to be accomplished.

Session VI
Biometeorology in Recreation and Land Use

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Problems Associated with Mountain Subdivision Living¹

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Abstract.--The population of the Colorado Front Range is growing rapidly. Above tree-line the mountain subdivision is commonplace. Houses are being built in dense stands of trees on steep slopes with little regard for aspect and drainage. Water may be in limited supply. These conditions yield high fire hazard and risk. Silvicultural practices can be used to reduce the danger to people and the site.

INTRODUCTION

The basic information supporting this paper was collected during the summer of 1973 when the author was a Visiting Professor under the Forestry School Faculty Employment Program with Region 2 of the U.S. Forest Service in Denver, Colorado. The objective of this paper is to delve into the problems encountered with living in a mountain subdivision and to present forestry guidelines which will enhance conditions and associated values for human living in mountain subdivisions. The Colorado Front Range from Fort Collins to Pueblo was the study area.

Subdivision Growth

The population of Colorado has grown by approximately 150 percent since World War II. A high percentage of this growth has been along and adjacent to the front range. The mountain subdivision has become commonplace. There are thousands of mountain subdivision lots already platted, but the best estimates indicate that less than 20 percent of these lots have been issued building permits.

Even though Colorado has initiated tighter land-use controls there appears to be little decline in interest in property. According to some sources the rate of growth in the mountains was double what it was in adjacent areas for the past 10-15 years. This means that the population is doubling on 20 percent of the lots.

¹/Paper presented at Fourth National Conference on Fire and Forest Meteorology, St. Louis, Mo., Nov. 16-18, 1976.

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Hazards

The majority of mountain subdivisions are located on forested slopes. Danger from natural phenomena (fire, insects, disease, avalanches, flood, etc.) are greatly compounded whenever man becomes a permanent or temporary resident.

Survival and vigor of a tree or a forest becomes more important once located on a house lot. A forester or rancher can tolerate the death of a small percentage of the trees in the forest and not become too concerned. Each tree is of importance on a house lot. Forest fires of low intensity may not destroy the trees and may be of minor concern.

Forest Fire.--There is no dramatic history of frequent and large forest fires along the front range but there is a past history of fire on practically all sites. Number of yearly fires on the Arapahoe, Pike and Roosevelt National Forests has been increasing.

From 1870 to 1910 there were large numbers of miners, ranchers, and loggers living in the mountains. Much of the land was apparently burned over and/or logged, as well as mined. Forest conditions were apparently conducive to fire and people were present in large numbers. Consequently, many of the forests seen today are between 70 and 100 years old and are even-aged. The author counted the annual rings on various stumps and found the majority of them to be about 80 years old.

Conditions today appear to be similar to those that existed between 1870 and 1910. This may indicate a 100-year cycle, possibly 120-year, for severe forest fire conditions along the front range.

Hulbert (1972) reported that seventy-five percent of the people concerned with mountain subdivisions interviewed in Boulder and Jefferson Counties felt the forest fire danger was low or only moderate in the mountains of Colorado. Also, 75 percent of the respondents felt that there would be no evacuation problems if there were a forest fire. Hulbert further states, "Although seventy-five percent of the people interviewed did not believe there was a serious fire hazard where they lived, 92 percent indicated they would take necessary precautions to reduce fire hazards if someone would convince them of the problem and show them what to do."

Insects.--Mountain pine beetle, ips beetle, and western budworm are three insects which are currently attacking front range forests. Statistics for seriousness of infestation, damage and loss to forest stands are limited.

Disease.--There are only limited estimates of the impact of disease on the forests of the front range. Dwarf mistletoe on ponderosa and lodgepole pines are probably the most prominent pest along the front range. Although it takes years to kill a tree, the overall effect can be highly detrimental.

Aspect (Exposure).--Direction the slope faces is a prime factor in the suitability of a lot from a health and safety viewpoint. Many lotowners have purchased their lots during the summer and find that the winter conditions are much more severe than they expected.

North Slopes.--The north slope is normally the cooler and more moist aspect of the four and added snow accumulation may be visual proof. North slopes with lower temperatures and higher humidities have a thicker humus layer on the soil and larger materials decompose into punk, etc. sooner than the same sized materials on south and west exposures.

Species composition is also affected by the aspect. For example, Douglas-fir, true fir, and spruce are commonly found on north and east slopes, and ponderosa pine, pinyon-juniper, or sagebrush are more characteristic of south and west slopes.

On the average the north slope is the least critical, from a fire hazard standpoint, because of the lower temperature and humidity. However, if and when a fire does occur, the site may be damaged severely.

South and West Slopes.--The south and west slopes are normally more critical from a fire hazard standpoint because these exposures are more likely to have more frequent fires. Under the same fire danger rating, the rate of spread

on a south and/or west slope can be expected to exceed that on a north slope because of a more severe microclimate.

Ownership

The reasons for owning a forested mountain subdivision lot are highly variable. However, there are at least four types of ownerships. There are: year-round occupancy, seasonal occupancy, absentee, speculator.

Year-around Resident.--The year around dweller is going to be much more concerned, at least should be, with health, safety, and aesthetics than the other three types. Several factors make this owner a more approachable client. These are: availability, continual awareness and desire to improve living conditions.

Seasonal Resident.--The seasonal dweller may be using the site because it makes recreational facilities, such as skiing, readily accessible. Because of limited occupancy, often for a predetermined reason, this type of owner is not normally inclined to invest time and/or dollars in health, safety and aesthetics.

Absentee.--The absentee owner, providing they occasionally visit the property, may have some aesthetic motivations, but little concern for health and safety. As a consequence, even if these people could be contacted, they normally would be reluctant to invest time and money to improve conditions on their property.

Speculator.--The speculator has little desire to invest any additional money on his property. In many cases these owners rarely visit the land--possibly many have never visited the lot. This type of owner has essentially no desire to improve site conditions.

Legislation

Whenever recommendations are prepared to improve health and safety for people and trees, it is important to know if the subdivision was established before or after stricter local or state regulations. Some regulations are now in effect which did not have any influence on older subdivisions.

Other Considerations

Water Availability.--Lots platted before regulations required water supply certification may not have any water available on the site. Other lots that meet the regulations may have only a minimal supply. In some cases there are ample supplies of water, particularly if there is a public water service.

Original Condition of the Site.--The appearance and condition of the forest at the time it becomes a subdivision is very important. If the subdivision is in a dense forest, conditions will be entirely different than if it is an open park-like site.

Condition of the forest floor is also important. If there is very little ground cover and essentially no down dead material, this is not as critical as if there is a mass of material on the ground.

Rate of Accomplishment.--Development may be done in a short time or extended over a long period. Construction is normally done in a short period of time. Improvement of health, safety and appearance factors of the forest on a subdivision lot may be accomplished over a much longer period of time. Except where there is danger of windthrow or other such factors, it would be desirable to reduce stand density as rapidly as possible. Time and money may not be available to rapidly accomplish the task, but the owner should strive to reduce stand density to an acceptable level during a three to five year period. The task should take no more than ten years.

Amount of Treatment.--One of the most difficult questions to answer is "How much of the subdivision or other land area must receive proper treatment to truly achieve the level of health and safety needed?" The individual lotowner should not despair. Although the lot may be far from the optimum size area for treatment, if it is treated properly, the odds are greatly improved. A homelot that has had good forest management applied to it offers the people and the trees a much better health and safety factor.

DISCUSSION

With all of the previous considerations in mind, the problem of making guidelines seemed almost an impossibility. On the one hand, we had technological information supporting a need for certain treatments and on the other hand the problem of getting anything accomplished. Recommendations must be initiated on the basis of what is needed from a technical standpoint and modified as the subdivider or owner acceptance factors dictate.

The Goals

The goal of forest management on the mountain subdivision and/or lots should be (1) to remove most of the dead material over 1/4 inch in diameter from the site, (2) to reduce stand density to the lowest level which is compatible with the ownership objectives,

(3) and to reduce the flammability of the resulting grass by cutting or irrigation.

Disposal of Material

Whenever practices are applied to a stand, there is merchantable and non-merchantable material to dispose of. Merchantable material may be as much of a problem as non-merchantable. It is desirable to remove all, or most of the material from the site. Firewood may be stacked and utilized on the site.

Non-merchantable Material.--Tops, branches, stumps, etc. are most often unwanted for any use. It is doubtful if any great amount of this material could be burned in the fireplace before it deteriorated. The most common ways of disposing of this material are: chipping, burning, burying and removing. These four methods are all costly and/or time consuming.

Merchantable Material.--Firewood seems to be a viable and profitable product, but there are few contractors cutting trees for firewood. The cut product can usually be sold if stacked roadside.

Sale of poles, posts, and sawlogs is dependent on local conditions and the amount of material to be sold. The subdivider or possibly a homeowners association is in a better position to negotiate the sale of products of this type.

Techniques Available

There are many silvicultural techniques available for improving the safety, aesthetics, and survival of the subdivision lot for people and trees. The basic problem encountered on most of the lots is that there are too many trees present, which results in stands of low vigor, containing large amounts of dead and dying woody material.

Forest Housekeeping.--Forest housekeeping (intensive cleaning-up) is seldom used in a managed forest stand. It is desirable to remove the major portion of all the dead, flammable material from the site. This technique is difficult to evaluate in normal silvicultural terms.

To achieve the optimum in forest fire protection, it is necessary to remove most of the dead material over 1/4-inch in diameter from the forest floor, prune most of the dead limbs from the trees, and control flash fuels.

Thinning.--Making a profit from the thinning operation itself is often questionable even under the best of forest management operations. Nevertheless, thinning may produce some

immediate income.

Pruning.--Pruning of lower limbs from trees is desirable. Removal of dead limbs can reduce the fire ladder factor, make the stand easier to move through, and improve appearance. Pruning is also important in control of dwarf mistletoe.

Planting.--It should not be assumed that stand density is always too high. There are many areas which are too open and it is desirable to plant trees and/or shrubs. Planting of trees and shrubs can furnish shade which will reduce the amount of grass, a flash-type fuel.

Fertilizing.--Soils in mountain subdivision have relatively low nutrient levels. Fertilization may improve the health and vigor of trees and shrubs. Fertilization may have to be done in conjunction with irrigation to achieve acceptable results.

Irrigation.--If precipitation is limited during the growing season, irrigation will aid health and vigor of trees and likelihood of fire ignition and spread is reduced.

Constructing Fuelbreaks.--Fuelbreaks are desirable around and through a subdivision. Access and a place to more easily "make a stand" are important reasons for their existence. These fuelbreaks can be arranged so that they are not obvious and do not affect the aesthetics of the area. A fuelbreak could also prevent movement of an isolated crown fire across the lot.

Constructing Firebreaks.--Because of land values and aesthetics, it will normally not be feasible to construct true firebreaks. A firebreak is constructed to stop or at least reduce fire spread. In areas of high hazard or risk, such as fire chimneys, firebreaks should be constructed. The road network and firebreak network may be incorporated. A firebreak could be part of the common open space of the subdivision. An effective firebreak would, in most cases, be too large to be placed only on a small house lot.

Prescribed Fire.--If prescribed burning was done under the proper conditions before homes were constructed, fine ground fuels could be reduced and the danger could be reduced for a few years.

Spraying.--Because insects, such as the mountain pine beetle, are difficult to control by natural means, spraying may be necessary. Cost of spraying may be more justifiable on a house lot.

Site Factors

Basic factors considered in these silvicultural guidelines are: density of materials, location and distribution of dead plant material, amount of dead plant material, and species of forest type.

Stand Density.--Stand density can vary from bare ground to a site covered by vegetation. On the mountain subdivision lot, it is not very desirable to have a zero or a 100 percent extreme. From existing data and opinions, the conclusion was made that stand density should be the lowest level consistent with ownership objectives, site and species requirements. Table 1 indicates percent reduction in burning index by reducing stand density. This data is based on starting with very dense stands and it is reasonable to relate stems per acre with volume of burnable material, excluding boles of trees. If a tree is removed, volume is removed.

Table 1.--Sample results if stand density of a dense* stand of ponderosa (lodgepole) pine is reduced**.

Treatment	%Reduction in Burning	
	Grass Out	Grass Allowed
Remove 30% of trees	17	10
Remove 50% of trees	23	12
Remove 70% of trees	28	14

* "dog-hair" type stand.

**Unpublished data compiled by M. Fosberg of the Rocky Mt For & Range Exp Sta, USFS

Blowdown.--Heavy cutting and resulting lower stand densities should not result in severe windthrow or other adverse results on small treatments such as subdivision lots. Cutting of trees on lots in subdivisions should be coordinated in order to prevent opening up too large an area. With current ownership patterns and activity, it is doubtful that large areas of low density will result. Alexander (1973) states: "On the Fraser Experimental Forest, windfall losses were light and other mortality negligible after partial cutting removed about 45 percent of the total basal area by a modified shelterwood cut, even though the stands were exposed to windstorms that nearly destroyed adjacent, partially cut stands with less residual basal area."

Location of Dead Fuel.--If the dead fuel in a stand is on the forest floor and extends up into the canopy the fire danger is more severe. Most forest fires start as surface fires and consume the fine fuels on the ground. If there is a fuel ladder and adverse weather conditions, then a crown fire may result.

Amounts of Fuels.--Obviously the more available the fuel the greater the probability of having a fire. If one consults the National Fire-danger Rating System Manual, Research Paper RM-84, it can be demonstrated that the ignition component (a number related to the probability that a spreading fire will result if a firebrand encounters fine fuel) is the same for all fuel models if the same conditions of the state of weather, dry bulb temperature, and fine fuel moisture are assumed. This indicates that, if the same conditions exist in two different fuel types, the likelihood of a fire igniting are the same; however, burning factors will vary. Amount of fuel available for combustion is significant.

Whenever tons per acre of fuel are considered, it can readily be shown that the more difficult fire control conditions exist in heavy fuels. Table 2 demonstrates a comparison among the various fuel models.

Amount of flash-fuels, such as grass, are of major importance. These flash-fuels are easy to ignite and readily carry a fire, although they are relatively easy to suppress. Table 3 indicates the effects of fuel moisture (irrigation possible) and volume of fuel on fine fuel moisture, which greatly affects flammability.

The larger the number in Table 3, the more easily the fire is suppressed. It can be concluded that if the area has a high percentage of green grass and a high moisture percentage, fire danger will be much lower.

Although there may not be a great accumulation of pine needles in the ponderosa and lodgepole pine stands, it is still possible to get up to a 30 percent reduction in burning index if the needles on the forest floor are completely removed.

Forest Types.--Most of the mountain subdivisions are located in one of the following types of vegetation: pure ponderosa pine, pure lodgepole pine, mixed pine or mixed conifer, pure aspen, mixed conifer-hardwood, pinyon-juniper mixture, spruce-fir mixture, brush and grass.

Table 2. Maximum fire danger values based on tons per acre of fuel*.

Fuel Model	Description	100-hour				Bed		Spread Index	Energy Release	Burning Index
		1-hour	10-hour	100-hour	Live	Depth	Live			
A	Grasslands	1.25	0.0	0.0	0	0.75	0	100	19	12
B	Dense brush	5.00	4.0	2.0	2	6.00	2	87	100	100
C	Open overstory	1.50	1.0	0.0	0	1.00	0	74	34	41
D	Less than 2" diameter	1.50	2.5	2.0	0	2.50	0	33	31	50
E	Hardwood; conifer-hardwood	1.50	1.0	0.0	0	0.30	0	16	36	21
F	Low flammability brush	1.00	0.5	0.0	2	2.00	2	13	11	8
G	Dense conifer	3.00	2.0	5.0	0	1.25	0	13	85	58
H	Green foliage; compacted	1.00	1.0	1.0	0	0.40	0	7	34	26
I	Clearcut conifer areas	4.00	5.0	10.0	0	3.50	0	28	96	90

*Unpublished data from the National Fire Danger Rating Team of the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Table 3. Sample fine fuel moisture percentage relationships for a grass fuel model*
1-hour Time Lag Herbaceous Vegetation Condition %
Fuel Moisture

Percent	Vol. Green Fuel		X 100
	Vol. Green	Vol. Dead	
	5-14	35-44	75+
1	2	5	21
9-10	12	19	24
25+	25+	25+	25+

*From page 43 of Research Paper RM-84, Rocky Mt For & Range Exp Sta, Ft Collins, Colo.

RECOMMENDATIONS KEY

Problems

Earlier attempts to prepare a key which would include forestry recommendations for all situations and conditions encountered on the mountain subdivision resulted in a practical impossibility. There were so many ramifications to the problem that the initial key was too cumbersome to be useful. Later efforts were also essentially useless unless a computer was available. Under these circumstances, results would have been difficult to apply in the field.

Consequently, it is necessary for foresters and other professionals to make initial judgments and assessments and be involved in problems encountered on a particular subdivision before practical recommendations can be made.

Using the Key.--The key is an attempt to give some guidance in solving the problem of a particular subdivision or lot. These guidelines should not be considered to be normal silvicultural recommendations for a typical forest stand.

To use the key it is necessary to determine the following: (1) ownership--determined by personal contact or county records, (2) property size--from owner, measurement or county records, (3) stems per acre--determined by sampling, (4) forest type--determined by observation, (5) amount of dead material on the site--determined by observation.

Key

1. Owner, a year-around resident - - - - - 2
1. Owner, not a year-around resident - - - - - 25
2. Property size, less than 2 acres - - - - - 3
2. Property size, more than 2 acres - - - - - 6
3. Trees, less than 1,000 per acre - - - - - 4
3. Trees, more than 1,000 per acre - - - - - 9
4. Coniferous forest type - - - - - 5
4. Conifer-hardwood forest type - - - - - 12
5. Dead material, low to moderate amount - - - - - A
5. Dead material, moderate to high amount - - - - - A

6. Trees, less than 1,000 per acre - - - - - 7
6. Trees, more than 1,000 per acre - - - - - 13
7. Coniferous forest type - - - - - 8
7. Conifer-hardwood forest type - - - - - 16
8. Dead material, low to moderate amount - - - - - A
8. Dead material, moderate to high amount - - - - - A
9. Trees, 1,000 to 5,000 per acre - - - - - 10
9. Trees, over 5,000 per acre - - - - - 17
10. Coniferous forest type - - - - - 11
10. Conifer-hardwood type - - - - - 19
11. Dead material, low to moderate amount - - - - - B
11. Dead material, moderate to high amount - - - - - B
12. Dead material, low to moderate amt - - - - - D
12. Dead material, moderate to high amt - - - - - D
13. Trees, 1,000 to 5,000 per acre - - - - - 14
13. Trees, over 5,000 per acre - - - - - 20
14. Coniferous forest type - - - - - 15
14. Conifer-hardwood forest type - - - - - 22
15. Dead material, low to moderate amount - - - - - B
15. Dead material, moderate to high amount - - - - - B
16. Dead material, low to moderate amount - - - - - D
16. Dead material, moderate to high amount - - - - - 18
17. Coniferous forest type - - - - - 18
17. Conifer-hardwood type - - - - - 23
18. Dead material, low to moderate amount - - - - - C
18. Dead material, moderate to high amount - - - - - C
19. Dead material, low to moderate amount - - - - - E
19. Dead material, moderate to high amount - - - - - E
20. Coniferous forest type - - - - - 21
20. Conifer-hardwood forest type - - - - - 24
21. Dead material, low to moderate amount - - - - - C
21. Dead material, moderate to high amount - - - - - C
22. Dead material, low to moderate amount - - - - - E
22. Dead material, moderate to high amount - - - - - E
23. Dead material, low to moderate amount - - - - - F
23. Dead material, moderate to high amount - - - - - F
24. Dead material, low to moderate amount - - - - - F
24. Dead material, moderate to high amount - - - - - F
25. Owner, a seasonal resident - - - - - 26
25. Owner, absentee - - - - - 49
26. Property size, less than 2 acres - - - - - 27
26. Property size, more than 2 acres - - - - - 30
27. Trees, less than 1,000 per acre - - - - - 28
27. Trees, more than 1,000 per acre - - - - - 33
28. Coniferous forest type - - - - - 29
28. Coniferous-hardwood forest type - - - - - 36
29. Dead material, low to moderate amount - - - - - A
29. Dead material, moderate to high amount - - - - - A
30. Trees, less than 1,000 per acre - - - - - 31
30. Trees, more than 1,000 per acre - - - - - 37
31. Coniferous forest type - - - - - 32
31. Conifer-hardwood forest type - - - - - 40
32. Dead material, low to moderate amount - - - - - A
32. Dead material, moderate to high amount - - - - - A
33. Trees, 1,000 to 5,000 per acre - - - - - 34
33. Trees, more than 5,000 per acre - - - - - 41
34. Coniferous forest type - - - - - 35
34. Conifer-hardwood forest type - - - - - 43
35. Dead material, low to moderate amount - - - - - B
35. Dead material, moderate to high amount - - - - - B
36. Dead material, low to moderate amount - - - - - D
36. Dead material, moderate to high amount - - - - - D
37. Trees, 1,000 to 5,000 per acre - - - - - 38
37. Trees, over 5,000 per acre - - - - - 44

38.Coniferous forest type - - - - -	39
38.Conifer-hardwood forest type - - - -	46
39.Dead material,low to moderate amount -	B
39.Dead material,moderate to high amount-	B
40.Dead material,low to moderate amount	D
40.Dead material,moderate to high amount	D
41.Coniferous forest type - - - - -	42
41.Conifer-hardwood forest type - - - -	47
42.Dead material,low to moderate amount	C
42.Dead material,moderate to high amount	C
43.Dead material,low to moderate amount -	E
43.Dead material,moderate to high amount-	E
44.Coniferous forest type - - - - -	45
44.Conifer-hardwood type- - - - -	48
45.Dead material,low to moderate amount -	C
45.Dead material,moderate amount- - - -	C
46.Dead material,low to moderate amount	E
46.Dead material,moderate to high amount	E
47.Dead material,low to moderate amount -	F
47.Dead material,moderate to high amount-	F
48.Dead material,low to moderate amount	F
48.Dead material,moderate to high amount	F
49.Property size,less than 2 acres- - - -	50
49.Property size,more than 2 acres- - - -	61
50.Trees,less than 1,000 per acre - - - -	51
50.Trees,more than 1,000 per acre - - - -	53
51.Coniferous forest type - - - - -	52
51.Conifer-hardwood forest type - - - -	56
52.Dead material,low to moderate amount	A
52.Dead material,moderate to high amount	A
53.Trees,1,000 to 5,000 per acre- - - -	54
53.Trees,more than 5,000 per acre - - - -	57
54.Coniferous forest type - - - - -	55
54.Conifer-hardwood forest type - - - -	59
55.Dead material,low to moderate amount -	B
55.Dead material,moderate to high amount-	B
56.Dead material,low to moderate amount	D
56.Dead material,moderate to high amount	D
57.Coniferous forest type - - - - -	58
57.Conifer-hardwood forest type - - - -	60
58.Dead material,low to moderate amount	C
58.Dead material,moderate to high amount	C
59.Dead material,low to moderate amount -	E
59.Dead material,moderate to high amount-	E
60. Dead material,low to moderate amt-	C
60.Dead material,moderate to high amount	C
61.Trees,less than 1,000 per acre - - - -	62
61.Trees,more than 1,000 per acre - - - -	64
62.Coniferous forest type - - - - -	63
62.Conifer-hardwood forest type - - - -	67
63.Dead material,low to moderate amount -	A
63.Dead material,moderate to high amount-	A
64.Trees,1,000 to 5,000 per acre- - - -	65
64.Trees,more than 5,000 per acre - - - -	68
65.Coniferous forest type - - - - -	66
65.Conifer-hardwood forest type - - - -	70
66.Dead material,low to moderate amount	B
66.Dead material,moderate to high amount	B
67.Dead material,low to moderate amount -	D
67.Dead material,moderate to high amount-	D
68.Coniferous forest type - - - - -	69
68.Conifer-hardwood forest type - - - -	71
69.Dead material,low to moderate amount -	F
69.Dead material,moderate amount- - - -	F

70.Dead material,low to moderate amount-	E
70.Dead material,moderate to high amount	E
71.Dead material,low to moderate amount-	F
71.Dead material,moderate to high amount -	F

RECOMMENDATIONS

This series of recommendations attempts to cover fully developed lots to completely undeveloped lots, meadows to dog-hair stands, etc. Therefore, a forester must temper the resulting recommendations with his knowledge of ecology, silviculture, etc.

The forester must also keep in mind the ownership objectives, (1)aesthetic, (2)safety, and (3)a compromise. What is best may not be feasible, and the recommendation must be adjusted to fit that particular situation.

RECOMMENDATION A - Coniferous forest type
with less than 1,000 stems.

General.--This recommendation can be reached 12 different places in the key, but any of the 12 results will yield a coniferous forest with less than 1,000 trees per acre. Silviculturally these should receive similar treatments on similar sites.

Stems per Acre.--Because of the range of stand density covered in this recommendation, planting may often be more necessary than thinning. The goal should be to have an open, park like stand, but with sufficient crown cover to prevent the fine fuels from becoming hazardly dry.

Forest Type.--Since this is a pure coniferous type, hardwoods and shrubs should be planted to avoid problems encountered with pure or two-specied stands. The heterogeneous stand will improve the condition for wildlife, reduce fire hazard, and should improve aesthetics.

Dead Material.--Depending upon the volume present, most of the fine dead fuels should be removed. Larger materials may be left for wildlife cover, but the continuity and arrangement must be broken up to reduce its ability to support combustion and to reduce the likelihood of insects breeding in the material.

Insects and Disease.--The presence of insects and disease will limit the alternatives and the degree of intensity of silvicultural practices. Caution must be exercised to avoid mortality and/or spread of the problem.

RECOMMENDATION B - Coniferous forest with 1,000 to 5,000 stems per acre.

General.--This group is probably the one which will most frequently be encountered.

Variability encountered will be great and a forester must use his on-the-ground knowledge to solve an individual situation.

Stems per Acre.--Depending upon the original stand density, the stems should be reduced by 50 to 70 percent of the original. Local conditions, such as windfirmness, will determine the rapidity of removal. If the property is small and there is little or minimal treatment on adjacent properties, thinning and housekeeping should be done during one season. The goal is to avoid a continuous crown canopy.

Forest Type.--Since dense, pure coniferous forests are being manipulated, stand composition should be changed. Planting of shrubs will improve wildlife habitat, reduce fire hazard and improve the appearance of the lot.

Dead Material.--Since a relatively large volume of slash will be created by thinning slash and dead material should be cleaned up and disposed of in one operation. All fine fuels should be removed. Larger material may be left for wildlife cover and aesthetics. Continuity and arrangement of larger fuel must be considered.

Insects and Disease.--This level of stand density is likely to have an insect and/or disease problem. If sizable reductions in stand density are made, caution should be exercised to protect remaining trees. Disposal of removed and dead material will greatly increase the odds. Spraying and other techniques may be necessary.

RECOMMENDATION C - Coniferous forest with over 5,000 stems per acre.

General.--These stands are much too dense for good tree growth. Reduced vigor can result in larger amounts of burnable material and conditions conducive to insect and disease attack. This density also makes it possible for a crown fire to readily burn through the stand when the proper conditions exist.

Stems per Acre.--It is questionable whether it is possible to reduce the stand density to a desirable level in one operation. The reduction should be accomplished in a three to ten year period. The extended period may not be optimal from reduced fire hazard and increased vigor considerations, but may be mandatory in order to obtain an acceptable forest stand. Often these stands may be so stagnated that a reduction in stand density will have a minimal influence on stand vigor. Since this is a very dense stand the goal should be to reduce it to 1,000 stems per

acre or the lowest amount feasible which will meet the ownership and ecological demands. If the stand is reduced from several thousand stems per acre to one thousand during a several year period, then conditions and appearance should be greatly improved.

Forest Type.--This type is over-stocked coniferous stands. The two most common types represented are lodgepole pine and spruce-fir. Health and vigor is less than desirable and often the stands have stagnated. Silvicultural treatment is needed to improve growth conditions as well as safety factors.

Dead Materials.--Since these stands are dense, there is normally a thin covering of litter and debris on the forest floor. Flash fuels are limited. Lower dead limbs on the tree will frequently remain attached to the tree and a fire ladder can result. Proper thinning and pruning will eliminate most of the hazardous dead material. If a substantial amount of "down" material remains on the forest floor, the major portion of it should be removed.

Insects and Diseases.--Since these stands are often stagnated, they may be susceptible to insect and disease attack. Thinning, pruning, and removal of the flash should make these stands more resistant to insects and disease.

RECOMMENDATION D - Mixed stands with less than 1,000 stems per acre.

General.--In the natural state, this should be the most desirable group from a health and safety viewpoint. Because of the lower density and the presence of hardwoods, fire, insect, and disease potential is lessened, at least in severity.

Stems per Acre.--Density may be acceptable as it occurs. Thickets should be thinned and open areas should have some shrubs planted in them. If the trees are evenly scattered over the area, removal of "in the way" trees and cleaning up of the site may be sufficient.

Dead Material.--Depending upon stand history, there will most likely be a low volume of fine fuels. All fine fuels should be removed from the site. Removal of larger fuels is optional.

Insects and Disease.--Because of the open condition and diversity of species there is a minimum of danger from insect and disease outbreaks. Sanitation and a prevention program should prevent any serious loss.

RECOMMENDATION E - Mixed type, 1,000 to 5,000 stems per acre.

General.--Mixed forest type with densi

General.--Mixed forest type with densities in this range are indicative of clumps or thickets of very high densities, because it is unlikely that there would be an even distribution of all species. Even though small acreages may be involved, stratification of these stands is recommended and then the various strata treated under separate recommendations.

Stems per Acre.--Strata mentioned above will probably yield some dense areas. Overall stand density should be reduced by 50 to 70 percent of the original density, but some areas would be less and some more than this. Species diversification should be as great as possible on the site.

Forest Type.--The more species present the more acceptable the stand will be from a health and safety standpoint. Encouragement of all species present and the planting of others will yield greater results.

Dead Material.--Down dead material may not be as voluminous as in the pure stand, but there may be more dead limbs on the trees to act as fuel ladders. Fine fuels should all be removed from the site. Larger dead material may be left at the discretion of the owner, providing there is no large or continuous concentration.

Insects and Disease.--As a result of reduced vigor, insects and disease may be present in the stand. If they are present, infected trees should all be removed first. Once infected trees and other trees are removed, prevention programs should be initiated.

RECOMMENDATION F - Mixed type with over 5,000 stems per acre.

General.--On small properties, it is doubtful if this situation would exist, but if it did exist, it would most likely be in clumps of pure species. Stratification should be done, even on an acre basis.

Stems per Acre.--Once the area is stratified, the goal should be to reduce the stems

per acre to 50 to 70 percent of the original density or to leave no more than 1,000 stems per acre. Caution should be exercised not to thin any one portion of the lot too severely. It will probably take a minimum of five years to satisfactorily accomplish this task.

Dead Material.--All fine fuels should be removed from the site. It is questionable whether there would be a large volume of larger dead material on this type of site. As long as it is not piled there is little need for concern.

Insects and Disease.--A good sanitation and prevention program will most likely prevent any serious loss to either insects or disease.

SUMMARY

Information was collected during the summer of 1973, under Forestry School Faculty Summer Program, Region 2, United States Forest Service. The study was to evaluate existing and potential forestry conditions on mountain subdivisions on the Front Range of Colorado and then make recommendations for improving safety and survival of people and trees.

Factors encountered were: 1) many homes were constructed in hazardous forest conditions, 2) many lots were platted which could be developed without any controls from recently passed legislation, 3) forests along the front range have been reasonably well protected from fire, but management practices have not been as efficient.

Six recommendations, based on silvicultural techniques, and presented in a key, which if followed should improve the hazardous conditions.

LITERATURE CITED

- Alexander, R. R. 1973. Partial cutting in old-growth spruce-fir. Rocky Mountain Forest and Range Experiment Station Research Paper RM-110. 16 p.
- Hulbert, J. 1972. Fire problems in rural suburbs. American Forests, Vol. 78, No. 2, p. 24.

Meteorology and Ski Area Development and Operation¹

M. Martinelli, Jr.^{2/}

Abstract.--Although it is obvious that ski areas must have adequate snow cover, the importance of early-season snows and of frequent snows during the winter is often overlooked. Wind affects lift operation, and erosion and deposition of snow on the mountains and around facilities. Temperature and snow deposition patterns affect building design in the mountains. Other weather-related phenomena that should be considered include temperature inversions and avalanches.

INTRODUCTION

Skiing now has between 5 and 7 million devotees in the United States. The industry has been growing rapidly, and the prospects are considered good for continued growth. In the past 10 to 15 years, the trend has been toward the large destination-type ski resort such as those at Aspen, Vail, Snowbird, Stowe, and Stratton Mountain. These resorts are complex year-around mountain communities complete with homes, restaurants, hotels, shops, and usually with a full complement of police, fire, sanitary, and hospital facilities. The large, glamorous areas such as those just mentioned and the numerous smaller day-use areas have several things in common. Both are trying to deliver a quality recreational experience to their customers, and both are highly sensitive to the vagaries of weather.

EARLY SEASON SNOWCOVER

The most obvious and most important single meteorological factor in ski area development is the snow cover. To be financially successful, ski areas must have a good snow cover early in the winter. Public demand for skiing starts in mid November in the Rocky Mountain area and about then in most other areas. The Christmas-New Years vacation period is one of the heaviest use periods of the entire season.

During the 1975 Christmas season, for example, Vail had its biggest single day, with 12,000 skiers on the mountain at one time. It is during this early season rush that the financial success or failure of most areas is decided. Often the snow cover is only marginal at this time of year, and it would be best if sustained heavy skiing could be postponed until the base was deeper and more complete. Limiting ski use, however, is usually ruled out by the clamor of skiers wanting to get started, and especially by the inn keepers whose lodges and hotels are often booked solid by eager customers who have been convinced skiing starts on the first of November and lasts until early June. This misapprehension about the length of the ski season comes from the tendency of the ski areas and lodges to list the earliest and latest dates of skiing for the entire period of record as though they are guaranteed dates every year.

Thus we see that one important meteorological feature to be aware of in ski area development is not just snow cover, but early season snow cover. Potential new ski areas should be surveyed and carefully checked for skiable snow cover during mid-December, not on some sunny March or April day as is so often done.

The early-season demand for skiing, in spite of the unreliable snow cover, has lead to the complicated and intensive ski-trail grooming operations so prevalent on American ski slopes today. Trails are laid out and groomed so the first snows of autumn can be packed by snow cats pulling rollers and graders. The idea is to be able to open at the first heavy frost. A smooth trail is important because the snow will be thin over the high spots in an uneven trail. These thin spots

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quickly become bare under heavy ski traffic, especially if the weather warms up.

In addition to early-season grooming, most American ski areas carry out several types of intensive snow grooming throughout the winter. It is common practice, for example, to machine-pack new snow as it falls. This keeps the wind from blowing it off the old ski-packed surface and toughens it against displacement from ski traffic.

In spite of machine packing, sustained heavy ski traffic results in an uneven snow surface, especially on the steeper parts of the trails. This is accentuated by the wide acceptance of the short ski and the stiffer ski boot. This equipment makes it possible (and fashionable) for skiers with only modest skills to ski the steeper slopes. When this type skier gets in steep terrain, he tends to go farther out of the fall line and usually slides his turns more than an expert skier. As a result the skis push the loose snow into mounds, called moguls, which enlarge with time. Eventually the steeper portions of the trails are completely covered with moguls. For many skiers, such mogul fields are difficult and unenjoyable. To smooth such areas, large graders pulled by snow cats chop off the tops of the moguls and drag the loosened material into the troughs. Generally this operation is successful. At times, however, when the tops are cut off the moguls, the snow beneath is so coarse-grained and loose as the result of metamorphism that it spills down slope and leaves a bare spot. This condition requires additional grooming and packing, which is easier if there is new snow to mix with the older, granular snow.

Artificial snow-making is still another grooming practice recently installed in many areas. Special snow guns release a mixture of compressed air and water that forms snow crystals under proper weather conditions. At some areas entire trails are covered with artificial snow--at other areas only certain chronic trouble spots. As far as I know, there are no special meteorological problems associated with artificial snow-making so long as temperatures are below freezing and winds are not so strong they displace the snow.

There is no doubt the smoothed, well-groomed ski trails contribute to the enjoyment of most skiers. Skiing these well-manicured and engineered trails does wonders for the ego and confidence of all but the most skilled skiers, who may wish more of a challenge. The earth-moving and grading necessary to produce such trails, however, often create serious problems that only become apparent during the spring

thaw. Forest litter, low vegetation, and small natural drainages are often damaged by the grading so the melt water starts to erode the exposed soil. Water bars, artificial drains, and revegetation are necessary to stabilize the slope. Stabilization is often difficult and, at best, may take several years, especially at the higher elevations. In the meantime, there may be severe erosion on the slopes and in the overloaded stream channels.

FREQUENT SNOWFALL

Thus a second meteorological factor that is helpful for ski-area development is frequent snow falls all during the ski season. These snows are needed to repair the damage done by the ski traffic and to build additional base. Strange as it may first appear, very large snowfalls are often more of a hindrance than a help. A storm of 18 to 24 inches requires around-the-clock packing and grooming on the mountain, as well as extra effort to plow the parking lots and access roads. Such heavy storms also create problems on the major highways, often substantially increasing driving time from the population centers to the ski areas. They are also major factors in the release of snow avalanches which pose a threat to many ski areas and access roads.

WIND

Wind is another meteorological factor of considerable importance to ski-area development. Wind patterns in mountainous terrain are notoriously complex. An important contribution meteorologists could make to ski-area development is to devise ways to determine what wind-flow patterns will be on a mountain after considerable timber has been cut in strips down the mountain for ski trails, lift lines, and building sites. One engineering approach reported in the literature uses a scale model of the mountain and a sediment-laden water flume (Matthews 1975).

Wind erosion and deposition of snow plagues many ski areas, especially those that extend above timberline. Wind-scouring of the snow is particularly serious when steep pitches face the prevailing winds. Such places seldom get a heavy snow cover in the first place, and what they do get is loosened by the sliding action of the skis and carried away by the wind. On trails downwind of sparse or patchy timber, the snow cover is often uneven with scoured places alternating with deep drifts. Near the crest of ridges, snow is characteristically blown from the windward to the leeward side. This leaves the windy side too rocky to ski, and often creates cornices or dangerous

avalanche-prone snow-cushions on the lee side. Wind-scour also makes it necessary to shovel snow onto the unloading ramps of many lifts, or to cover the ramps with some artificial but skiable material --- such as rope netting or outdoor carpeting. The other extreme is exemplified by one large western ski area where the top terminal building for one of the lifts is buried in a snow drift and must be entered via a snow tunnel, while less than 100 yards away snow fencing is needed to provide enough snow to get the skiers started down the mountain. Good trail locations with careful attention to wind flow patterns can avoid many such problems; snow fences or other wind barriers have been helpful in numerous places. A few of the really tough problem areas, however, have resisted all efforts so far.

High winds also create safety problems for all types of aerial lifts. Winds blowing across lift lines cause the chairs, gondolas, or trams to swing and at times to become entangled in the towers. The only safe procedure is to stop operating the lifts when certain wind velocities are reached. Failure to do so has resulted in several lift accidents and numerous near misses.

As most skiers can testify, wind is also an important factor in skier comfort. Chair-lift rides of 15 to 20 minutes are common on the bigger mountains. Only a few of these lifts have any type of protection for the riders. During cold weather, especially if snow is falling, a breeze of 15 to 20 miles per hour can lead to severe discomfort and at times to frostbite. The drag lifts such as T-bars and Pomas that keep the skiers on the ground and out of the wind, or the enclosed gondolas or trams, are much better for such conditions.

TEMPERATURE

Temperature is a third meteorological factor important in ski-area development. Warm temperatures soften the snow and quickly lead to poor skiing and eventually to bare spots. Alternating warm and cold temperatures, typical of sunny high elevations in the spring, result in snow conditions that vary greatly not only from place to place on the mountain at any given time but also from time to time at any given place. It is particularly annoying to be skiing down a trail and find your skis sticking and dragging in wet mushy snow in the sunny spots and shooting out from under you on the icy snow in every patch of shade. Warm mid-winter temperatures indicate the possibility of rain, and rain on snow is bad news at ski areas. During and immediately after the rain

the snow is wet and heavy. It quickly turns to ice, however, as soon as the temperature drops. Both conditions are difficult and unpleasant to ski. Rain also loads the steeper slopes, weakens the snow, and sometimes leads to avalanching. Extremely cold temperatures (-25°C or -10°F) on the other hand, are not only uncomfortable and dangerous for the skier but also make the snow unusually hard and "sandy" under the skis. This type of snow is unpleasant and tiring to ski.

One of the many enigmas of the ski business is that, although cold temperatures are important for quality skiing, warm temperatures are preferred for the areas to be developed for hotels and houses. A steep north-facing mountain with a relatively broad valley that allows the sun to warm the lower south slopes makes a nice arrangement. When valley elevations are low, however, it is good insurance to design the lower ski lifts so skiers can ride the lift down the mountain. This allows skiing on the upper trails well after the lower trails are melted out.

ADDITIONAL METEOROLOGICAL FACTORS

Additional ski area problems that involve meteorology include proper architectural designs for snowy regions, temperature inversions, whiteout conditions, and snow avalanches.

There are a number of important factors when designing buildings for snowy regions (Bull 1973). Roof design is of primary importance. Typically heat leaks through the roof and melts some of the snow on the roof. The melt water runs down the roof until it encounters the cold eaves. Here it freezes. Additional melt water ponds up behind the ice dam and flows under the shingles into the building. The only solution is to have either a completely warm or completely cold roof. A warm roof must have heat piped all the way out to the eaves. Even then small ice dams usually form. A cold roof is really a double roof with a space for outside air to circulate between them. Both of these solutions are expensive. Yet the obvious shortcut of eliminating the eaves has proven disastrous. An ice dam still forms and causes early leaks plus icicles that tend to hit the building and break windows when they fall.

Any pitched roof should have the gables (ends) pointed toward the prevailing winds to reduce snow drifts that result in uneven loads and serious design problems. Doors, walkways, or other places where people congregate should be at the ends of the building and not under sloping roofs. The current trend is toward flat roofs with a gentle slope toward a center

drain down through the warm building. The wind keeps most of the snow blown off the roof, and the simple shape makes design problems easier. I know of one building with a complex, ornate roof that has so many ice dams and icicles the management eventually installed electric heating elements in the numerous gutters and roof valleys. At another area, the snow on the roof of the upper gondola terminal forms two large cornices. One cornice overhangs the area where people stop to put on their skis; the other overhangs the door to the first aid room. This building has since been modified to reduce these hazards.

The intense temperature inversions typical of snow-covered mountain valleys become very noticeable and troublesome when the number of homes and auto traffic increases. Smog around the base area at some of the ski resorts has recently become so bad that serious thought is being given to prohibiting the use of all fireplaces during temperature inversions. This would be quite a blow to the classic image of mountain homes and après ski life in which fireplaces figure prominently.

Flat light or whiteout conditions occasionally become severe enough to curtail skiing and greatly restrict highway driving. Whiteouts occur during blowing snow events in snow-covered, treeless areas. The uniform, diffuse light with no shadows, no dark objects, and no horizon gives the impression of floating in a big bowl of milk. When this condition develops on the ski slope, one quickly loses all perspective of slope steepness and motion. It is very disconcerting in steep terrain to be certain you are standing motionless or moving very slowly on your skis, only to have your arm whip back suddenly when your ski pole touches the snow.

I'll only mention here that snow avalanches are a safety problem along some mountain roads and in some ski areas. Avalanches result when the snow load on steep slopes exceeds the strength of the snow. The amount of snow and its strength at any given time, and the changes that take place with time, are correlated with weather conditions. Perhaps the interesting topic of snow avalanches can be discussed at some other time.

MOUNTAIN WEATHER FORECASTS

Short-term mountain weather forecasts have been notoriously poor for most western mountain areas. To some extent this reflects the higher priority set on forecasting for the more heavily populated, nonmountainous areas. To some extent it may also reflect the lack of good mountain reporting stations or the added difficulty of

forecasting for the more complex terrain. Whatever the reasons, the fact is that, at this time, the day-to-day operations on most ski areas are carried out with an almost complete disregard for weather forecasts, and the skiing public has little information on which to make its decisions. The greater number of people in the mountains and the fine communication systems that now exist on many of the larger ski areas mean more possibilities for good mountain reporting stations than ever before. To be most useful, mountain weather forecasts should cover conditions on the ridges and mountain tops, not just valley locations. Snowfall amounts, durations, and intensities, temperatures, wind speeds, and stability conditions are the primary features that will allow the ski areas to schedule their work crews and the skiers to make their travel plans.

A FEW NON-METEOROLOGICAL FACTORS

Although we have been discussing meteorological problems, the successful location and development of a new ski area involves many problems that are unrelated to meteorology. For example, the availability of private lands for the base area and for real estate development is extremely important. Other important considerations are: easy access by public and private transportation from large population centers; proximity to other successful ski areas; sufficient long-term financing at reasonable rates; and evaluation of the impact to be expected on the environment and local economy. These and other economic, political, and social problems as well as the meteorological problems we discussed must be dealt with early in the planning process.

SUMMARY

In summary, I feel there are two major meteorological problems that are important for ski area development and smooth operation.

1. The prediction of the localized wind patterns to be expected on a given mountain if a certain set of trails and lift lines are built.

Certain trail and lift locations are dictated by the terrain and general area layout but many are not. In either case it would be highly desirable to be able to consider the wind factor when choosing among several possible trail patterns and in determining the final details of trail width and alignment pitch by pitch down the mountain.

2. Detailed and quantitative 24-hour forecasts of precipitations, wind and atmospheric stability conditions for specific ski areas.

Precipitation forecasts would help greatly in scheduling manpower and equipment for grooming, snow plowing, avalanche control, and artificial snow making. Wind forecasts are important for lift safety and for the operation of certain lifts that run only during good weather. Stability forecasts are becoming important for anticipating temperature inversions severe enough to require restrictive measures to reduce smog and air pollution in the valleys.

LITERATURE CITED

- Bull, Henrik
1973. The trouble with winter. Ski Area Manag. 12(2):49-51,90.
Matthews, Dan
1975. New snow simulator predicts control and design. Ski Area Manage. 14(2):56-57.

The Application of Forest Edge Meteorology to Environmental Impact Assessment and Development Planning¹

David R. Miller²/

Abstract.--The components of the two dimensional energy budget at a hardwood forest edge are presented and analyzed. Field experiment results indicating the magnitude of the various energy budget components at forest-development interfaces are presented. The usefulness and application of this type of knowledge to aid with the minimization of the local environmental impact of developments in forested areas is discussed.

INTRODUCTION

Urban encroachment into forested areas is one of the major land use changes occurring in the eastern U.S. Over the years urban and suburban designers have suggested leaving "green belts" or other arrangements of natural vegetation as a rather vaguely defined environmental buffering system.

Recently there have been numerous attempts to institute programs which would routinely assess the environmental impact of "proposed" local developments before the developments are begun. These efforts have been quite valuable in pointing out which disciplines lacked information that can be applied on a practical local basis.

For example, the Connecticut Environmental Review Team described by Miller and Thomas (1974) has made on site impact assessments of some 80 proposed developments in rural eastern Connecticut. Approximately 80% have been in forested areas. In all of these cases the limitations of the soil and

microhydrological systems involved could be detailed from standard survey data with a minimum of on site data gathering. This was not true with regard to the meteorological effects of the developments. Local microclimate changes and their importance in the mesoscale air pollution or heat island could only be stated very generally. Little can be detailed on the effects of suburban vegetation, spaces and structures on the "microscale" meteorological processes.

The numerous mesoscale investigations of the urban atmospheres are difficult to transfer into specific design criteria for individual developments because they are an integration of the effects of the microclimatic patchwork. Local heat balance considerations are considerably more complicated than can be inferred from general average heat island data. The suburban or urban surface is dentated by streets, buildings with verticle walls and partial canopies variously exposed to solar radiation and each other. Figure 1 demonstrates some differences in surface temperatures that are common in this environment. It shows a parking lot surface reaching 50° C while a forest canopy wall facing the parking lot remains at about 20° C.

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It's this edge environment which so far has precluded the transformation of micrometeorological knowledge to engineering design criteria.

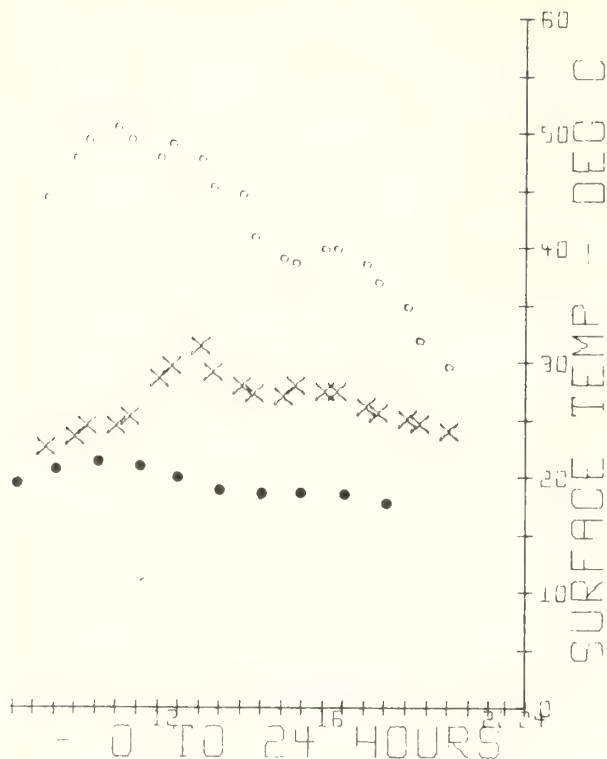


Figure 1.--Surface temperatures of an asphalt parking lot (o), a south facing, vertical oak forest wall (•) and soil beneath the forest (x).

We are approaching a technology transfer capability with regard to the local radiation regimes in this edge environment. A recent project by co-operators in the Pinchot Consortium for Environmental Forestry Research (Stark and Miller, 1975; Plumley, 1975; and Herrington and Vittum, 1975) has pointed out the roles of various arrangements of vegetation ameliorating the urban and suburban radiant energy environment. Figure 2 (from Stark and Miller, 1975) shows the relationship between radiant energy loads and the percentage of the hemispherical view in non-natural conditions (vegetation, sky). It demonstrates the type of relationship definition that is necessary for local decision makers to judge the tradeoffs being made.

But the local radiation environment is only one part of the problem. The major source of confusion when defining the physical vegetation - development interactions is horizontal energy trans-

port or advection.

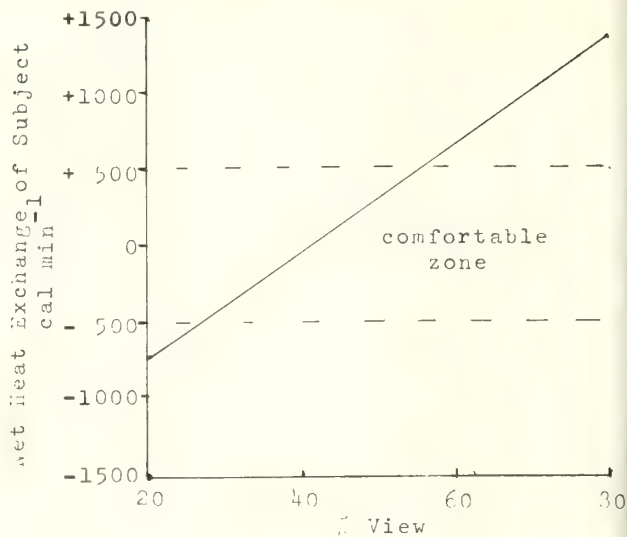


Figure 2.--Average summer midday net heat flux for a human subject as a function of the proportion of his hemispherical view covered with synthetic materials (i.e. cement, brick, etc.), Storrs, Connecticut.

Tanner (1958) described two different ways in which advected energy is supplied to plants. First, the energy is supplied to the canopy vertically from an overlying mass of advected air. He called this the "oasis" effect. The second is the case where advected energy, generally sensible heat, is moved horizontally through the canopy. This he called the "clothesline" effect.

The three dimensional form of the forest-urban interfaces, together with the large amounts of sensible heat produced in the urban settings, suggests the possibility that horizontal advection into and from adjacent stands may be significant. If these exchanges can be defined then the secondary effects of this energy exchange can be predicted.

THE TWO DIMENSIONAL ENERGY BUDGET

The energy exchanges of a volume of forest of height (h) located at a stand edge are diagrammed in Figure 3. The forest exchanges radiation (R_n), latent heat (E), and sensible heat (A) both vertically (subscript z) and horizontally (subscript x) with the sur-

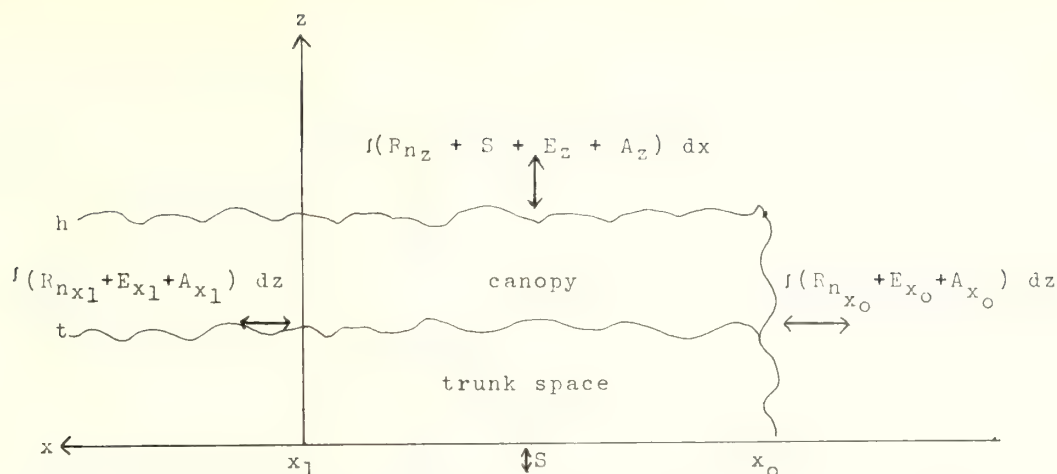


Figure 3.--Diagram of the two dimensional energy budget at a forest edge.

rounding atmosphere. There are also horizontal and vertical exchanges of these entities between various parts of the canopy. At the lower boundary heat is exchanged with the soil (S).

The steady state balance of the energy gains and losses of the edge cross section of height (h) and extending from the edge (x_o) some distance (x_1) into the forest can be written:

$$\begin{aligned}
 0 = & \int_{x_o}^{x_1} (R_{nz} + E_z + A_z + S) dx \\
 & + \int_{z=0}^{z=h} (R_{nx_o} + E_{x_o} + A_{x_o}) dz \\
 & - \int_{z=0}^{z=h} (R_{nx_1} + E_{x_1} + A_{x_1}) dz \quad (1)
 \end{aligned}$$

If the horizontal distance $x_1 - x_o$ is large enough to avoid edge effect and the horizontal divergence of R_n , A and E can be assumed negligible beneath the canopy of a homogenous forest, then the third term of equation (1) can be neglected reducing it to:

$$\begin{aligned}
 0 = & \int_{x_o}^{x_1} (R_{nz} + E_z + A_z + S) dx \\
 & + \int_{z=0}^{z=h} (R_{nx_o} + E_{x_o} + A_{x_o}) dz \quad (2)
 \end{aligned}$$

Verticle Exchange

The verticle components of the energy balance above the edge forest canopy are the same processes as those normally described above agriculture and forest canopies. But the proximity to the edge affects the quantities involved in the verticle exchanges due to the variations in the internal boundary layer thickness. (See Plate, 1967; Montieth, 1973; and Rosenberg, 1974 for discussions of the boundary layer). The rate at which the boundary layer grows with distance from the abrupt change in roughness caused by a stand edge varies somewhat with the type of surfaces involved. In the case of hardwood forests, Shinn (1971) calculated, from Sadah's (1974) measurements of shear stress in a wind tunnel with a simulated forest edge, that the disturbed boundary layer thickness (γ) and the internal boundary layer thickness (γ') (as defined by Plate, 1967) grew identically and linearly with distance from the leading edge up to 25 h (h = tree height):

$$\Delta\gamma = .08x \quad (3)$$

Since the boundary layer depth is a function of distance from the stand's leading edge the conditions will change with wind direction. If the wind is blowing from the stand the edge volume will probably be well within the internal boundary layer equilibrated to the canopy.

R_{nz} and S are not effected by proximity to the forest edge. But E_z

and A_z are functions of the boundary layer depth.

Evapotranspiration measurements in low growing plants downwind from a dry edge have been made several times (Rider et al, 1963; Hand, 1964; Millar, 1964; Dyer and Crawford, 1965; Lang et al, 1974) and always showed decreasing vapor-flux with distance from the edge. The form of the relationship is an asymptotic one first suggested by Philip (1959). He suggested that E_z would vary downwind from a dry boundary according to:

$$E_z = ax + b \quad (4)$$

In equation (4) a , p , and b are constants. " a " is the amplitude of additional evapotranspiration at the edge caused by the availability of advected (horizontally transported) sensible heat (A) at the edge. " p " describes the rate of decay of this amplitude downwind and is probably uniquely related to the internal boundary layer thickness (γ').

" b " is not really a constant but is the E flux rate in the interior of the stand where the internal boundary layer has fully developed. In this case the interior evapotranspiration rate (b) can be described by the commonly used, one-dimensional flux-profile relationships within the boundary layer.

$$\beta = \frac{A_z}{E_z} = \frac{\rho C_p}{L} \left(\frac{K_a}{K_e} \right) \frac{\partial T / \partial z}{\partial e / \partial z} \approx \frac{\rho C_p}{L} \frac{(\Delta T)}{\Delta e} \quad (5)$$

and

$$b = \frac{R_{nz} - S}{1 + \beta} \quad (6)$$

Where: T is air temperature
 e is vapor pressure of water in air
 K_a is an exchange coefficient for sensible heat
 K_e is an exchange coefficient for water vapor
 ρ is air density
 C_p is the specific heat of air at constant pressure
 L is the heat of vaporization of water

Combining equation (4) and (6) gives:

$$E_z = ax + \frac{R_{nz} - S}{1 + \beta} \quad (7)$$

Where $\frac{\Delta T}{\Delta e}$ is measured with adequate downwind fetch from the edge.

Sensible heat flux (A_z) downwind from the edge will be produced at the top of the canopy by two different processes. One is the sensible heat produced by contact of the air with the radiationally warmed canopy. The second is sensible heat forced (advected) through the stand edge which is transported upward through the canopy.

The amount of sensible heat available to flux upward will dissipate with distance into the stand. Therefore the sensible heat transport with depth into the stand (x) will decay in a similar manner to E , i.e.:

$$A_z = c x^{-d} + e \quad (8)$$

Where c and d are constants and e is the verticle sensible heat flux above the canopy in the interior of the stand where it can be described by the verticle gradients and partitioning the verticle energy balance:

$$e = \frac{R_{nz} - S}{1 + 1/\beta} \quad (9)$$

$$A_z = cx^{-d} + \frac{R_{nz} - S}{1 + 1/\beta} \quad (10)$$

Horizontal Exchange

Sensible heat flux through the edge depends on the wind speed (u) and horizontal temperature gradients.

$$A_{x0} = \int_{z=0}^{z=h} \bar{u} \frac{dT}{dx} dh \quad (11)$$

Fritchen et al. (1970) and Raynor et al. (1974) have indicated from dispersion studies that the wind approaching a forest edge from a cleared area tends to split into two flow pathways - above the forest and into the trunk zone. With a smaller flow of air entering the side of the crown. Thus indicating that flow into the edge should be considered in two layers consisting of the trunk layer, of height t , and the crown layer of height, $h - t$:

$$A_{x_0} = \int_{z=0}^{z=t} \bar{u} (dT/dx) dz$$

$$+ \int_{z=t}^{z=h} \bar{u} (dT/dx) dz;$$

$$\frac{dT}{dx} > 0 \quad (12)$$

A similar expression for latent heat transport can be written:

$$E_{x_0} = \int_{z=0}^{z=t} \bar{u} \left(\frac{de}{dx} \right) dz$$

$$+ \int_{z=t}^{z=h} \bar{u} \left(\frac{de}{dx} \right) dz; \quad \frac{de}{dx} \geq 0 \quad (13)$$

Equations 11-13 assume that \bar{u} is the major component of transport through the edge when the wind is near normal to the edge.

A FIELD STUDY

A field study of these energy budget parameters was conducted during 1973-75 in Storrs, Connecticut. A south facing Black Oak forest wall adjacent to a large asphalt parking lot was used. Radiant energy fluxes and horizontal and vertical gradients of wind speed, air temperature and vapor pressure were measured. The site, experiments conducted, and data collected have been listed in two reports, Miller et al. (1975) and Miller (1976).

Figure 4 demonstrates the general magnitude and locations of the horizontal and vertical gradients at the edge. It shows midday two dimensional gradients of vapor pressure and temperature at the edge. The locations of these gradients change as a function of wind speed and direction.

During periods with the wind blowing from the stand the first terms of equations 7 and 10 can be ignored because in these cases the distance from the leading edge (x) is very large. Therefore utilization of the measured gradients and energy balance parameters in the second terms of equations 7 and 10 allow the estimation of sensible and latent heat flux. Figure 5 shows the energy balance from such a day, July 11, 1974.

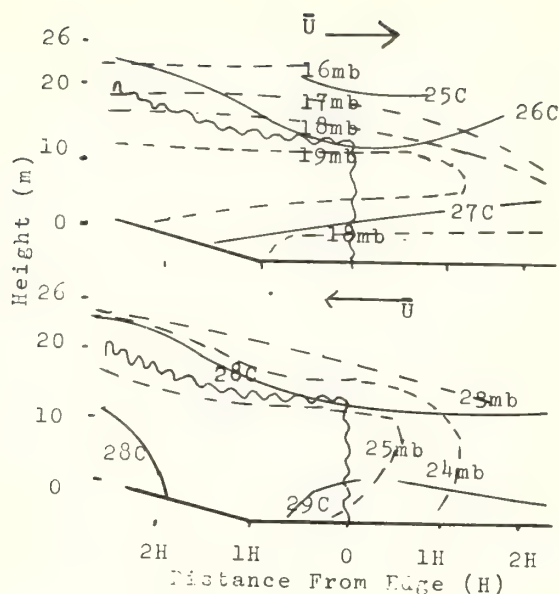


Figure 4.--Midday air temperature isotherms (solid lines) and air vapor pressure isobars (dotted lines) across the parking lot-forest edge with the wind blowing out of the forest, Aug. 22 (top) and into the forest, Aug. 24, 1974 (bottom).

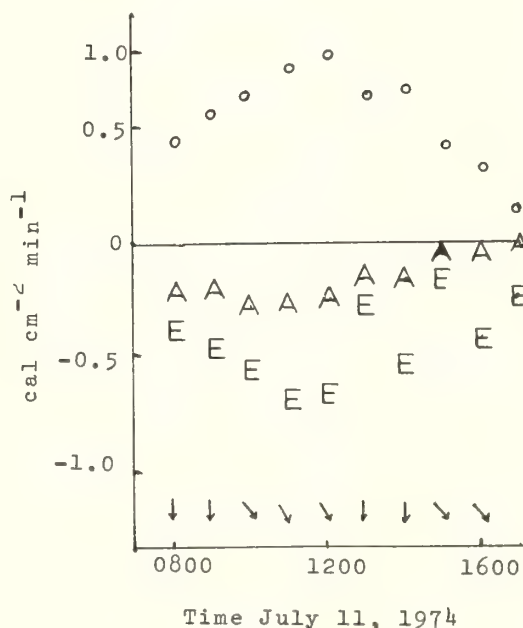
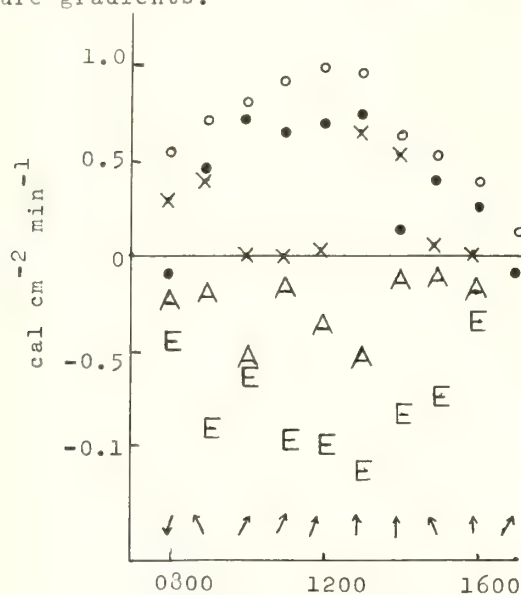


Figure 5.--Vertical energy budget with the wind blowing from the stand to the parking lot, July 11, 1974 (O is R_n ; E is E_z ; A is A_z ; and the arrows indicate wind direction).

Figure 6 shows the energy balance terms on a day (June 14, 1974) with the wind blowing into the stand. In this case energy is being added to the side of the stand. The amount of sensible heat advected into the side of the stand (A_x) was estimated by equation 12 utilizing the measured wind speed profiles at the edge and the horizontal temperature gradients.



Time June 14, 1974
Figure 6.--Energy budget with the wind from the parking lot to the stand, June 14, 1974. (o is R_{nz} ; • is R_{nx} ; x is A_x ; A is A_z ; E is E_z ; the arrows are wind direction).

R_{nx} was calculated from: the potential solar beam on a 90° south slope (R_{90}), after Fernival and Riefsnyder (1969); and atmospheric transmission factor (R_s/R_o), where R_s is the measured short wave radiation on the horizontal and R_o is the solar beam on the horizontal; and the on site determined regression of net radiation (R_{nz}) on R_s for the day.

$$R_{nz} = -.14 + .82 R_s \quad (14)$$

Thus,

$$R_{nx} = -.14 + .82 [R_{90}(R_s/R_o)] \quad (15)$$

(cal cm⁻² min⁻¹)

The energy budget shown in Figure 6 then is:

$$R_{nx} + A_x + R_{nz} - S = LE_z + A_z \quad (16)$$

Comparison of the two days gives an indication of the effects of the added energy on water use by the trees. On the day with the wind from the forest seventy-six percent of ($R_n - S$) was utilized to evaporate water ($\beta = .32$). On the day with the wind into the forest the evapotranspiration rate was approximately doubled. Sixty-nine percent of the total energy available ($R_{nx} + A_x + R_{nz} - S$) was used to evaporate water ($\beta = .45$).

The increase of β with the wind into the stand indicates that although the transpiration rate was increased a large proportion of the added energy was transported out through the top of the stand as sensible heat. Apparently energy was supplied faster than the trees were able to supply water.

PROBLEMS REMAINING

The edge energy balance research described above has given us some insight into some of the local environmental effects of development in woodland areas. But before the models can be utilized to predict effects of proposed developments at a given site the physical relationships involved in the first terms of equations (7) and (10) will have to be defined. The rates of decay, p and d , must be specified before the relative efficiency of any given geometric pattern can be determined. They are complicated functions of the edge momentum balance which is not understood.

Probably, the most immediate problem which is delaying practical applications is the lack of a method to independently measure short term transpiration rates in large trees. Not only do we need it to define parameters such as p but independent measurements of E are necessary to test the usefulness of present energy balance and aerodynamic techniques in the edge environment. Only Fritchen (1973) has made measurements of short term transpiration from a single large tree "in situ".

A continuing major problem is trying to predict microclimatic phenomena

on a site from general climate information with insufficient historical data both temporally and spacially.

SOME APPLICATIONS

If, through further research, we find that significant amounts of sensible heat can be advected through edge stands, and that the evapotranspiration response of the stands can be predicted, then applications can be made to several current land use problems. An obvious one is designing the most efficient arrangements of tree stands to reduce the urban heat island.

Another is in conjunction with land disposal of sewage effluent. The "living filter" system (Sopper and Kardos, 1973) does not work very well in areas like Connecticut which average only 20 inches of soil, 25 inches of annual evaporation and 40 inches of rain. Thus arrangements of land uses which might increase E in areas where land disposal of liquid wastes is proposed would be very helpful.

Also, the fact that the vegetation limited the rate of water use in the above study brings to mind another possibility. Stand management criteria might be established to increase or decrease evapotranspiration of edge stands. If the sensible heat moving through the edge would move further horizontally before rising through the canopy, more of it might be utilized to evaporate water. This might be accomplished by removing understory obstructions and edge vegetation while maintaining a solid overstory.

Bergan (1975a, 1975b), Shinn (1971), Buffo (1972), Sadah (1975) and others have recently added considerably to our knowledge of air flow in forest openings and at edges. Their work together with the extensive body of knowledge of air flow around blocks and rows of trees (i.e. Van Eimern, 1964; Miller et al., 1975; Plate, 1970 and others) should allow the development of some specific guidelines for utilizing trees in urban areas for wind control.

Modification of the local vegetation geometry has a number of secondary effects. Consequences of vegetation management can be pointed out in such areas as energy conservation, human comfort, phenological cycles, and snow

control. But, an adequate knowledge of the basic energy and momentum relationships at local forest-urban edges is necessary before these effects can be detailed.

ACKNOWLEDGEMENTS

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LITERATURE CITED

- Bergan, J. D.
1975a. The wind flow in an isolated forest clearing. Proc. 12th Conf. on Forest and Ag. Meteorol. AMS. Tucson, Ariz.
- Bergan, J. D.
1975b. Air movement in a forest clearing as indicated by smoke drift. Ag. Meteorol. 15:165-179.
- Buffo, J. M.
1972. Characteristics of velocity components near and at the edge of a forest. MS Thesis, Univ. of Wash., Col. of Forest Resources.
- Dyer, A. J. & T. V. Crawford.
1965. Observations of the modification of the microclimate at a leading edge. Q. J. R. Meteorol. Soc. 91:345-348.
- Fritschen, L. J.
1973. Dew fall on a Douglas fir. Paper presented to the 11th Conf. on Forest and Ag. Meteorology. Durham, N. C.
- Fritschen, L. J., C. H. Driver, C. Avery, J. Buffo, R. Edmonds, R. Kinerson, and P. Schiess.
1970. Dispersion of air tracers into and within a forested area: 3. Res. & Devel. Tech. Rept. ECOM-68-G8-3.
- Furnival, G. M., W. E. Reifsnyder, E. Wyler & T. G. Siccoma.
1969. Solar climate calculation. Proc. 3rd Forest Microclimate Symposium. Quebec Alberta.
- Hand, D. W.
1964. Advective effects on evaporating conditions as hot air crosses irrigated lucerne. Empire J. Exp. Agri. 32:263-273.
- Harrington, L. P. & J. Vittum.
1975. Human thermal comfort in urban outdoor spaces. Proceedings of

- the Conference on the Metropolitan Physical Environment. U.S.F.S., N.E.F.E.S. Bul. (In Press).
- Lang, A. R. G., G. A. Evens & P. Y. Ho.
1974. The influence of local advection on evapotranspiration from irrigated rice in a semi-arid region. *Ag. Meteorol.* 13:5-13.
- Millar, B. D.
1964. Effects of local advection on evaporation rate and plant water status. *Aust. J. Agric. Res.* 15:85-90.
- Miller, D. R. & H. F. Thomas.
1974. Land use planning. *J. of forestry*, Vol. 72 No. 4.
- Miller, D. R., C. A. Gallo, M. E. Frye, & C. S. Vavrina.
1975a. Research in microclimate at the forest-urban interface. *Progress Rept. #1*, Storrs Agr. Exp. Sta., University of Connecticut, 73p.
- Miller, D. R., N. J. Rosenberg, & W. T. Bagley.
1975b. Wind reduction by a highly permeable tree shelterbelt. *Agr. Meteorol.* 14:321-333.
- Miller, D. R.
1976. Research in microclimate at the forest-urban interface. Energy balances and advection at an asphalt-forest edge. Storrs Ag. Exp. Sta. Rept. to the Pinchot Consortium for Environmental Forestry Research. (In Press).
- Montieth, J. L.
1973. Principles of environmental physics. Amer. Elsevier Inc., N.Y.
- Plate, E. J.
1967. Diffusion from a ground level line source into the disturbed boundary layer far downstream from a fence. *Int'l. J. Heat and Mass Transfer* 10:181-194.
- Philip, J. R.
1959. The theory of local advection. *I. J. Meteorology* 16:535-547.
- Plumley, H.
1975. The design of outdoor urban spaces for thermal comfort. *Proc. of the Conf. on the Metropolitan Physical Environ.* U.S.F.S., N.E.F.E.S. Bul (In Press).
- Raynor, G. S., J. V. Hayes & E. C. Ogden.
1974. Particulate dispersion into and within a forest. *Boundary-Layer Meteorology* 7:429-456.
- Rider, N. E., J. R. Philip & E. F. Bradley.
1963. The horizontal transport of heat and moisture. *A Micrometeorological Study.* *Q. J. R. Meteorol. Soc.* 89:507-531.
- Rosenberg, N. J.
1974. Microclimate. The biological environment. J. Wiley & Sons, N.Y.
- Sadah, W. Z.
1975. Simulation of flow above forest canopies. In: *Heat and Mass Transfer in the Biosphere Part I.* D. A. DeVries and N. H. Afgan. eds. J. Wiley & Sons, N.Y.
- Shinn, J. H.
1971. Steady-state two dimensional air flow in forests and the disturbance of surface layer flow by a forest wall. Ph.D. Thesis, Univ. of Wis., Dept. of Meteorology.
- Sopper, W. E. & L. T. Kardos, eds.
1973. Recycling treated municipal waste water and sludge through forest and cropland. Penn State Univ. Press, University Park.
- Stark, T. F. & D. R. Miller.
1975. The effect of vegetation in urban areas on human energy balance and comfort. *Proc. of the Conf. on the Metropolitan Physical Environ.* U.S.F.S., N.E.F.E.S. Bul. (In Press).
- Tanner, C. B.
1958. Factors affecting evaporation from plants and soils. *J. Soil & Water Cons.* 12:221-227.
- Van Eimern, J.
1964. Windbreaks and shelterbelts. *WMO Tech. Note* 59:188p.

Propagation of Noise in the Out-of-Doors¹

L. P. Herrington^{2/}

Abstract.--The current state of knowledge concerning the propagation of noise in the out-of-doors and the effects of vegetation on the propagation process are reviewed. Based on this knowledge suggestions are made for the partial solution of acoustic problems present in recreation areas. Proper acoustic planning can reduce noise complaints.

INTRODUCTION

Noise, or unwanted sound, is an ever-present part of the environment when people are present. In general, the more people, the more noise. Since by definition noise is unwanted, it is usually considered objectionable and designers and planners of recreational facilities should consider the acoustic environment early in the planning process.

The attempt is often made to use land forms and vegetation to control noise. However, at the present time the propagation of noise over and through forested land is only partially understood. In this paper I will review some of the basic findings of the last several years and will discuss the application of these findings to recreational land use planning. A great deal of this work has been carried out by scientists working with the U.S. Forest Service, Pinchot Institute, through the Consortium for Environmental Forestry Studies.

PHYSICS OF NOISE

Description

Noise, or acoustic energy, is described basically by quantity and quality. Ambient noise is the more or less steady noise normally present in a given area for which it is hard to determine the exact source. Intrusive noises are louder noises, such as horns, trucks in a stream of auto traffic, jack hammers, children

yelling, etc. Quantity is the energy in the noise signal while quality is the distribution of that energy over the acoustic frequency range of 20 to 20,000 Hz (Hz is for Hertz or cycles per second). Figure 1 compares both the quality (spectrum) and quantity of noise for a city street and a rural park. Quantity can be measured as Sound Pressure Level (SPL) and this measure is expressed in decibels. The SPL scale is related to the logarithm of acoustic energy and to the sensation of "loudness". An increase in SPL of 10db is sensed as a doubling of loudness. Measurements of SPL are usually made with instruments which can be made to respond to the various frequency components of a noise signal in a way similar to that of the human ear. Such measures are designated by dbA.

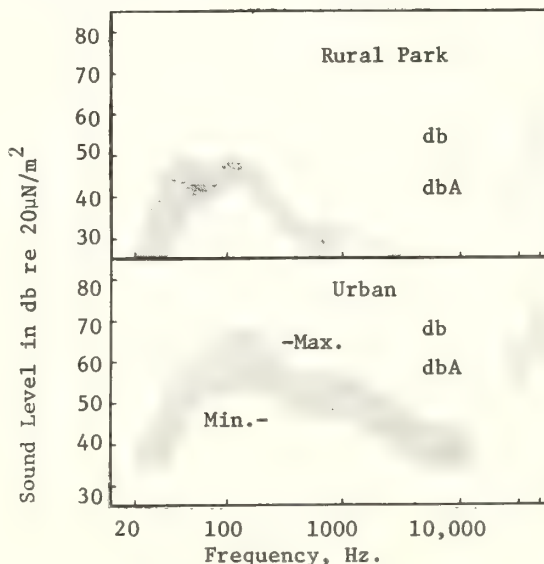


Figure 1. Third octave spectra, dbA, and db (flat, 20 to 20,000hz) for a typical urban area and a rural park. (Herrington 1974)

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Variation in sound level over time is another important characteristic of noise. The more variable the noise environment the more objectionable people find that environment. Generally increasing variability means increasing amounts of intrusive noise. The most common statistical description of this variability is the measurement of the sound levels which are exceeded 10, 50, and 90 percent of the time. In fact, the level which is exceeded 10 percent of the time alone has been found to be a good predictor of community reaction in some cases.

Other more complex estimators of community reaction, such as the Community Noise Equivalent level (CNEL), are adjusted for season (windows open or closed), ambient noise levels, and community attitude toward noise in addition to variability (EPA 1972).

Propagation

Acoustic energy is propagated through the atmosphere from a source to a receiver as a moving wave of atmospheric pressure variation. These waves spread spherically from the source with a resultant loss in energy per unit area. On the SPL Scale this results in a reduction of 6db for each doubling of distance. A truck which produces a SPL of 100db at 50 feet will produce levels of 94db at 100 feet, 88db at 200 feet, etc. In addition to the reduction of SPL with distance due to spherical spreading there will be reductions by scattering, reflection, refraction, diffraction and absorption of the acoustic energy. This additional attenuation is called excess attenuation. Excess attenuation in db loss per unit distance is the usual way in which the losses due to vegetation and land form are expressed. Another way to express these additional losses is by means of an insertion loss (McDaniels and Reethof 1975). The insertion loss is simply the difference in SPL measured with and without the presence of the structure being examined.

Atmospheric Effects

Both the wind and temperature structure of the atmosphere have important effects on the propagation of acoustic energy through the atmosphere. The velocity of sound varies directly with temperature. When the land surface is hot and the temperature of the atmosphere decreases with height (normal daytime condition), the acoustic wave will be refracted away from the surface since the wave front will travel faster near the surface. Under these conditions sound levels will decrease faster than expected with distance.

At night when the land surface is cold and temperature increases with height (inversion

condition) the acoustic waves will be refracted toward the surface with the result that noise levels will be higher than during the day; i.e. excess attenuation will be less. Wind has a similar effect since wind speed generally increases with height. Thus there is less attenuation for downwind propagation and greater attenuation for upwind propagation. Of the two the temperature effect is the more pronounced. The two effects can, of course, mutually cancel or add.

Effects of Vegetation on Noise

There has been considerable progress in recent years in developing an understanding of the propagation of acoustic energy out-of-doors (Herrington 1974) and of the role that vegetation plays in the propagation process. Acoustic energy can be propagated over or through vegetation with different losses. Vegetation can also add to the noise environment. Some pertinent results are summarized below.

1. For acoustic energy propagating beneath the forest canopy an excess attenuation of approximately 6db/100 feet (range 2db to 9db per 100 feet) has been found (Table 1). (Bjorenson 1971, Herrington and Brock 1976, Frank 1971, Leonard and Herrington 1973, McLoughlin 1975, McDaniels and Reethof 1975).

2. There tends to be more attenuation at the mid-frequencies (250-8KHz) than at higher or lower frequencies (Bjorenson 1971, McLoughlin 1975, Aylor 1972) but there is much inconsistency in the data (See Table 1). The most common pattern is for the high (2000-4000Hz) and low (125-250Hz) ends of the spectrum to be little attenuated while the mid-frequencies (250-2000Hz) are attenuated by approximately 10db/100 feet.

3. There is evidence that noise propagating over the forest is attenuated relatively little. Brock (1975) found an average excess attenuation of -0.1db/100 feet. Bjorenson (1971) noted that for sources outside the forest openings in the forest canopy resulted in a significant increase in sound level beneath the opening when the opening was at least as wide as the forest was high under inversion atmospheric conditions.

4. It has been shown that the forest floor is the absorbing medium in the forest. The more porous the surface the higher the absorption. Vegetation acts primarily as scattering elements (Aylor 1972, McDaniels and Reethof 1975). Scattering appears to be related to perceived aerial biomass (McLaughlin 1975).

5. Wind-break structures have been shown to produce insertion losses of about 10db and

Table 1.--Excess attenuation of selected cover types in order of increasing perceived aerial biomass.^{1/}

Type	dbh in.	Height ft.	Ave. Excess Attenuation per 100 ft. db re 20 μ N/m ²	Freq. of max. attenuation Hz	Notes
Bare Earth	-	-	1.2	500	unused road
Grass	-	-	1.2	250,1000	6-10 in. high
Hardwoods ^{2/} w/o foliage	1-26	50-70	3.8	250,2000-4000	brush understory
Red Pine ^{3/}	5-6	50-55	4.4	250-1000	plantation, 6 x 6 ft.
Hardwoods ^{2/} w/ foliage	1-26	50-70	5.2	250-4000	brush understory
Norway Spruce ^{4/} short	3-4	15-30	3.8	250-1000	plantation
Cedar ^{5/}	4-5	25-30	6.1	500-1000	visually dense
Norway Spruce ^{4/} open	5-6	45-55	5.6	250	natural pruning
Norway Spruce ^{4/} dense	5-6	40-45	8.4	250-4000	no pruning
^{1/} After McLaughlin 1975			^{3/} Pinus resinosa	^{5/} Thuja occidentalis	
^{2/} Northern hardwood type			^{4/} Picea abies		

barriers of berms and vegetation have also been shown to be effective (Cook and VanHaverbeke 1971, 1974). These conclusions were based on daytime data only, however.

6. Vegetation can produce "masking" sounds when wind rustles the leaves (Brock 1975, Dailey and Redman 1975). During the day in a moderate wind SPLs of 30 to 40dba can be produced while at night, under calm conditions, the ambient noise levels will be 20 to 30dba. This change in ambient level can change the "intrusiveness" of other noises. Running water is also a source of "masking" noise.

HUMAN RESPONSE TO NOISE

Basically people will be sensitive to the magnitude, quality, and temporal distribution of acoustic energy in a noisy situation. Generally, as the noise becomes louder, more people will complain and the complaints will become more vigorous. There is considerable variation in individuals' responses, particularly at low sound levels but when sound levels reach 70 to 80dba dissatisfaction will be high and there will be more consensus of opinion (EPA 1972). Sound levels which will trigger complaints will also depend on the expectations of the people.

Noises which are not tolerated in campgrounds may well be acceptable in the city - by the very same people! Application of the corrections made to the Community Noise Equivalent Level for ambient noise level and community attitude indicates that for people in rural areas sound levels of approximately 70 dba will result in vigorous complaints (65dba if the noise includes intermittent sounds) while there will be no reaction where levels are below 45dba. Dailey and Redman (1975) have specified "standards of insulation" for primitive, and portal situations in roadless area campsites. The standards are for the level of noises which will not be audible between camps and are, respectively, 48, 60, and 70dba. The more pristine the area the less noise is tolerated and the more attention must be paid to acoustic planning.

A very important aspect of the human reaction to the noise environment is the fact that people will be most sensitive to noise at night when ambient levels are low and intrusive sounds stand out. In addition, people expect quiet at night. A general rule of thumb is that acceptable noise levels will be 10dba lower at night than they were during the day (half as loud).

APPLICATION TO RECREATIONAL PLANNING

There are a myriad of noise problems which can and do occur in recreational areas. These range from the traffic noise problems of barren campgrounds next to interstate highways to people noises in wilderness areas. Generally, however, the problems will fall into one of two categories: problems resulting from noise sources outside the area and problems resulting from noise generated within the area.

In attacking these problems the four parts of the problem suggested by Dailey and Redman (1975) in their paper on campsite spacing form a good starting point. These are:

1. Identification of the intrusive noises which must be screened. Depends on type of facility and expectations of users.
2. Measurement or estimation of ambient noise levels.
3. Determination of the presence of, or possibility of construction of, attenuating structures.
4. Identification of site features which can block the visibility of noise sources.

To these I would add that there must be separate evaluations for day and night since both people and conditions will change with the time of day.

When 1 and 2 have been accomplished and the amount of attenuation needed has been estimated, attention can be directed to 3, which is the subject of this paper. How can existing knowledge of noise propagation and the role of vegetation in noise control be applied here?

In the case of noises originating outside the facility the best rule, assuming that the source can not be quieted, is one of distance. The further away the sources the lower the received sound level. Beware, however, of inversion conditions coupled with wind from source to receiver since under such conditions intrusive noises from distant sources can be heard and identified. This could be a problem in wilderness areas where people do not want to be reminded that other people, let alone highways or railroads, are around.

For campgrounds a second step is to see that the campsites are located beneath a closed forest canopy with few holes. This suggestion is based on the fact that acoustic energy passing over the forest is attenuated much less than that passing through the forest.

Sound levels will increase at night in the vicinity of large holes in the canopy.

The placement of areas requiring quiet so that barriers such as hills or ridges are between source and receiver will also help. The barrier should not be located midway between source and receiver but as close as possible to either one for maximum effectiveness. Under inversion conditions noise may still pass over the barrier and be refracted down toward the chosen site.

The masking sounds produced by moving water may be used to screen intruding noises. The closer the site to the water the more effective the masking since the sound of the water also decreases 6db for each doubling of distance.

In order to maximize attenuation of sound generated within the areas the amount of scattering and absorbing material must be maximized. This can be done by providing forest cover with considerable amounts of understory vegetation. The large amount of vegetation will result in a great deal of scattering of the sound and the understory vegetation will prevent compaction of the soil thus maintaining soil absorptivity. The understory vegetation will also provide visual screening and, in breezy conditions, provide additional masking. Given a site structure and an estimate of the excess attenuation provided by that structure the distance between campsites can be determined so that noises below a specified level generated at one campsite are not heard at the next under most conditions (See Dailey and Redman 1975).

In all of the above discussion I have treated only the acoustic aspects of the problems of recreational area planning. The solutions suggested here must, of course, be traded-off against other considerations.

SUMMARY

A little knowledge of outdoor acoustics can go a long way toward providing more acceptable recreation areas and should prevent many needless acoustic blunders. Facilities can be located to minimize the acoustic dissatisfaction of users. Although vegetation is no panacea for noise problems knowledge of the basic effects of vegetation on noise can allow successful application of vegetational control to some noise problems.

LITERATURE CITED

- Aylor, D. E.
1972. Noise reduction by vegetation and ground. J. Acoust. Soc. Amer. 51(1):197-205.
- Bjorenson, A. B.
1971. The effect of some meteorological conditions on sound propagation in three N. American forest types. MS Thesis. State University of New York, College of Environmental Science and Forestry. Syracuse. 103 p.
- Brock, C.
1971. Vertical acoustic energy profiles as affected by vegetation and atmospheric conditions. MS Thesis. State Univ. of New York, College of Environmental Science and Forestry, Syracuse. 93 p.
- Cook, D. I. and D. V. VanHaverbeke.
1971. Trees and shrubs for noise abatement. RB246, U. Neb. Col. Agr. Exp. Sta. Bull. 77 p.
- Cook, D. I. and D. F. VanHaverbeke.
1974. Tree-covered land forms for noise control. RB263. U. Neb. Col. Agr. Exp. Sta. Bull. 47 p.
- Dailey, T. and D. Redman.
1975. Guidelines for roadless area campsite spacing to minimize impacts of human-related noises. Pac. N.W. Fst. and Range Exp. Sta. Tech. Rpt. PNW-35. 20 p.
- EPA.
1972. Report to the president and congress on noise. GPO, Washington. (#5500-0040)
- Frank, R. A.
1971. The effectiveness of plants for highway noise abatement. Master of Regional Planning Report. Pa. St. U., University Park, Pa.
- Herrington, L. P.
1974. Trees and acoustics in urban areas. J. of For. 72(8).
- Herrington, L.P. and C. Brock.
1976. Propagation of noise over and through a forest stand. In: Proceedings of the Conference on Metropolitan Physical Environment. N.E. Fst. Exp. Sta. Upper Darby, Pa. In press.
- Leonard, R. E. and L. P. Herrington.
1971. Noise abatement in a pine plantation. USDA Forest Ser. Res. Note NE-40. N.E. Fst. Exp. Sta. Upper Darby, Pa. 6 p.
- McDaniels, O. H. and G. Reethof.
1975. The use of forests for noise control. Third Interagency Symposium on University Research in Transportation Noise. Univ. of Utah, November. Typescript.
- McLoughlin, K. T.
1975. PART I, Attenuation of noise by forest vegetation; PART II, Ambient noise levels in some common human environments. MS Thesis, State Univ. of New York, College of Environmental Science and Forestry. Syracuse. 105 p.

Air Pollution Potential in the Piceance Basin¹

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Abstract.--The assessment of air quality degradation caused by the anticipated development of oil shale in the Piceance Creek Basin of western Colorado was done by comparing the results from commonly used mathematical models and applicable air quality standards. Available emission rates combined with episode meteorological conditions produced ambient concentrations which would restrict full-scale operations if air quality standards are not to be violated.

INTRODUCTION

Our current standard of living is based upon the availability of inexpensive and abundant energy which we have enjoyed in the past. Fluctuations in availability have brought about cognizance of the fact that oil and gas reserves are limited in extent and that sources of supply are becoming less and less reliable. Questionable sources and fluctuating prices on the international market serve to enhance the desirability of becoming energy self sufficient to as high a degree as possible. Fortunately, the United States does have extensive oil reserves and needs not be wholly dependent upon foreign sources. If current domestic demands for oil are to be met in the context of energy independence, however, and if prices and supplies are controlled by foreign forces, then new domestic sources must be developed.

A domestic energy source not yet developed is the oil derived from kerogens locked within the extensive shale formations of Wyoming, Utah, and Colorado. The amount of oil believed recoverable from these shale deposits has been estimated at nearly one trillion barrels. Since the richest of the oil shale deposits are located in the Piceance Creek Basin of western Colorado, it is in this region where the first impacts from development will occur.

Technological considerations necessary for extracting oil from these shale deposits has been established for some time, and there have been pilot plants in operation demonstrating the technical feasibility of several different processes. Proposed production schedules suggest the possibility that pyrolysis plants capable of producing an estimated 150,000 to 250,000 barrels of oil per day could be in operation before 1985. Although these estimates are only a fraction of the anticipated full scale development of perhaps two million barrels per day, the impact that facilities of this size could have upon the air quality of the Piceance Basin may be significant. It is important, therefore, to obtain some idea of the carrying capacity of the regional atmosphere.

AIR POLLUTION POTENTIAL

The impact of development upon the air quality of a region depends upon two physical considerations: the amount of contaminant material injected into the air and the dispersive properties of the regional atmosphere.

Regional air pollution potential is determined by the interrelationships between meteorological factors and terrain configuration and is not related to ambient pollutant concentrations or sources within the region.

The air pollution potential is low if effective dispersal of contaminants occurs and conversely, if winds are light and the atmosphere is stable, the potential for air pollution would be greater (Shaw and Munn, 1971).

The worst situation for dispersal can be visualized when both persistent subsidence occurs and snow cover prevents adequate surface heating for the destruction of the radiation inversion for some time.

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In addition to general meteorological conditions, the atmospheric carrying capacity of a specific region depends upon the inter-related factors of large scale climatic controls and local topographic influences upon the micro-climate. The large scale climate of western Colorado is controlled by the combined effects of latitude, continentality, elevation, and location with respect to storm tracks. The influence of latitudinal control is exerted primarily through earth-sun geometry. Continentality is a measure of the distance to the nearest ocean controlling the amount of moisture an air mass contains when it reaches a specific region. Western Colorado is far from any major oceanic influence and is therefore subject to air masses which have traveled long distances across the dry intermountain states. Initial moisture from Pacific air masses is removed orographically by the coastal and the Sierra Nevada ranges creating an extensive rain shadow over most of the western states including the Piceance Basin region, and the storm tracks which could bring moisture from the Gulf of Mexico are effectively blocked by the Continental Divide of the Rocky Mountains to the east. In winter, continentality and the locations of these mountain ranges combine to make air masses reaching western Colorado quite dry and seldom severely cold (Marlatt 1973). During winter months the weather patterns are often dominated by large scale high pressure systems characteristic of mid-latitude continental regions. Associated with these high pressure systems are features of stability and subsidence which tend to reduce the dispersive capabilities of the regional atmosphere. A study done by Hosler (1961) indicated that stable conditions occur approximately 40 to 55 percent of the time in fall and winter, and 30 to 40 percent during spring and summer over the western Colorado region.

From an air pollution standpoint, the local topographical influences are also very important. The Piceance Basin is a bowl-shaped depression nearly 1800 km² in area which is extensively dissected by Piceance and Yellow Creeks and their tributaries. The two major streams flow northward to intersect the White River flowing westward to join the Green River in Utah. The configuration of the Basin is such that the only channels for cool air flow into the lower valleys are the narrow Piceance and Yellow Creek canyons. When microclimatic influences of calm or light winds and inversion conditions dominate the local weather pattern, air drainage is restricted. The cool dense air under the inversion layer forms deep pools in the lower Basin, and as a result of the stability of these cool air pools, a high potential for air pollution exists.

The combination of the presence of snow cover, a persistent high pressure system over the Piceance Basin, and the restrictions to drainage flow all contribute to the worst possible situation from an air pollution standpoint, that is, when these factors combine to allow the radiation inversion to become established and persist for more than a few hours. Although the frequency and duration of these situations are not well known for the Basin, enough data have been accumulated to show that these conditions indeed do exist across most mid-latitude continental regions and therefore would be expected over the Piceance Basin as well.

Quantification of the frequency and duration of high air pollution potential periods is difficult because the base, as in many remote regions, is severely lacking. Although precipitation and temperature records are available for certain locations in the Basin, long term records of other meteorological phenomena, especially wind speeds, are virtually nonexistent.

Inadequate meteorological data must be augmented by assumptions which do not contradict existing data or physical reality. Since episode or worst case conditions are the most important ones where human health is involved, the meteorological assumptions used in this impact assessment were made to represent such conditions. Light wind speeds were chosen to represent drainage flow conditions. Mixing depths were chosen to represent feasible conditions supported by the limited data available.

CONTAMINANT EMISSIONS ESTIMATES

Once the air pollution potential has been estimated, the remaining requirement which must be satisfied before the impact of oil shale development upon the air quality of the region can be assessed is that of estimating the amount of oil expected to be recovered from this resource in the near future. Knowing this amount and a range of alternative retorting schemes allows estimation of emissions into the atmosphere to be expected from these facilities.

Several techniques have been developed to extract oil from shale and detailed descriptions of these processes are available elsewhere (U.S. Department of Interior, 1973). Emission rates from the TØSCØ retorting process were used in this analysis.

Under ideal circumstances, meteorological data are available and the rates of contaminant emissions are known or can be directly measured. Under such conditions it is possible to monitor the ambient contaminant concentrations to determine directly the impact of a source upon the local air quality by comparing the measured

concentrations to the federal or state air quality standards. Such ideal conditions are the exception, however, especially in remote regions like the Piceance Basin where no previous industrial development has occurred on a scale to significantly affect the ambient air quality. In this region, there had been no reason to monitor the air quality or meteorological conditions until the development of an oil shale industry was assured. Direct measurements of ambient concentrations resulting from industrial activity are precluded in this case since there are no full scale facilities in operation in the Piceance Basin at the present time. Other methods are therefore required in making estimates of the ambient concentrations of pollutants and traditionally these estimates have been made through the use of mathematical models.

The most widely used statistical method of estimating contaminant concentrations from continuous point sources is the Gaussian plume model. In this method, the decrease in concentrations with distance away from the plume centerline is assumed to be due to random, independent particle motion. The resulting contaminant concentration across the plume can therefore be approximately represented by a double normal probability (Gaussian) distribution. Mathematically stated:

$$\Pr(x,y) = \frac{1}{2\pi\sigma_x\sigma_y} \exp\left[-\frac{(x - \bar{x})^2}{2\sigma_x^2} - \frac{(y - \bar{y})^2}{2\sigma_y^2}\right] \quad (1)$$

When meteorological symbols are substituted and the surface is assumed to be a perfect reflector, equation (1) becomes the classic Gaussian plume model (Turner 1970):

$$\begin{aligned} \chi(x,y,z) = & \frac{Q}{2\pi\sigma_y\sigma_z u} \left(\exp \frac{-y^2}{2\sigma_y^2} \right) \left(\exp \frac{-(z-H)^2}{2\sigma_z^2} \right. \\ & \left. + \exp \frac{-(z+H)^2}{2\sigma_z^2} \right) \end{aligned} \quad (2)$$

where $\chi(x,y,z)$ is the mass of contaminant per unit volume at (x,y,z) ; Q is the emission rate; σ_y and σ_z are standard deviations of pollutant concentration distributions in the horizontal and vertical directions, respectively; u is the mean wind speed; x , y , and z are Eulerian coordinates with the origin at the base of the emitting source; and H is the sum of physical height of the stack and plume rise.

In mountainous regions the plume from a continuous point source may be horizontally constrained by local topographic features, vertically trapped by an inversion layer, or effectively restricted by both. When thus restrained, contaminants become uniformly mixed both vertically and horizontally at relatively short distances downwind. Panofsky

(1969) used this concept in developing a simplified model where the concentration (X) varied directly with the emission rate (Q), and inversely with valley width (w), mixing depth (h), and wind speed (U) so that $X = Q/whU$. The volume contained by topographic features and the mixing depth is seldom completely sealed, however, but is ventilated through areas where the topography does not reach the height of the inversion layer.

Continuity requires that the time rate of change of mass within the box must be equal to the difference between the mass of pollutants emitted into the box and the mass per unit volume removed through the ventilation areas. In mathematical terms:

$$\frac{dM}{dt} = Q - V_r \frac{M}{V} \quad (3)$$

where M is the mass of pollutant, V is the box volume, Q is the emission rate (mass per unit time), V_r is the ventilation rate (ventilating area times wind speed), and M/V is the pollutant concentration (mass per unit volume). Solving for M/V produces:

$$\frac{M}{V} = \frac{Q}{V_r} [1 - \exp(-\frac{V_r}{V}t)] + \frac{M_0}{V} \exp(-\frac{V_r}{V}t) \quad (4)$$

where M_0/V is the existing concentration at $t = 0$.

The assessment of the impact on air quality involves methods combining both the air pollution potential which occurs under certain meteorological conditions and an inventory of contaminant emission rates to produce estimates of the ambient contaminant concentrations. Ambient concentrations were calculated using equations (2) and (4). The results were compared with applicable state and federal air quality standards.

AIR QUALITY STANDARDS

Known or suspected adverse effects depend upon certain levels of concentration and exposure times. The descriptions or technical statements of the effects of a pollutant under various conditions are called the air quality criteria for the pollutant. Air quality goals are even more encompassing and represent levels of concentrations below which no adverse effects are known to occur. Neither criteria nor goals have legal significance, however, but are important steps in the development of air quality standards. The 1970 Amendments to the Clean Air Act required the Environmental Protection Agency Administrator to establish primary and secondary air quality standards. Primary standards, based upon criteria as

defined above, were to be designed to protect the public health. Secondary standards, based upon air quality goals, were to be designed to protect the public welfare. The Administrator set federal primary and secondary air quality standards and most states have developed their own standards. Many states, in fact, have developed standards more stringent than national ones. These established standards become guidelines to which existing or projected contaminant concentrations may be compared. Those standards applicable to the Piceance Basin are provided in Tables 1 and 2.

RESULTS AND CONCLUSIONS

The assessment of the impact on air quality under episode conditions requires a comparison between the expected pollutant concentrations and the appropriate air quality standards. The federal or state standards applicable in this case are the primary air quality standards for an averaging time of 24 hours. These standards are not to be exceeded more than once per year. Colorado standards are separated with respect to designated and non-designated areas, and the Piceance Basin is classified as a non-designated area.

The Colorado, non-designated area, 24 hour maximum standard of $15 \mu\text{g m}^{-3}$ is the most stringent of the sulfur dioxide standards. Results from the box model show that a concentration of nearly $46 \mu\text{g m}^{-3}$ might be expected under conditions of a 305 meter mixing depth persisting for 24 hours. Stated differently, continuous operation of two retorting facilities each with a daily output of 50 thousand barrels beneath an inversion of 305 meters for 24 hours would create sulfur dioxide concentrations exceeding the Colorado standard by 300 percent. This standard would preclude any development of oil shale in the Piceance Creek Basin. The federal standard, by comparison, would allow a daily output of 400 thousand barrels or 8 plants, each with a daily output of 50 thousand barrels under similar conditions. If the average mixing depth of 458 meters were to persist for 24 hours, the Colorado sulfur dioxide standard would be exceeded by 135 percent. The federal standard would allow a daily production rate of 900 thousand barrels or 18 facilities producing at a daily rate of 50 thousand barrels. The federal 3 hour secondary standard of $1300 \mu\text{g m}^{-3}$ will probably not be exceeded in the Piceance Basin if the TOSCØ process is used.

A three hour averaging time federal standard also exists for total hydrocarbons ($160 \mu\text{g m}^{-3}$), but concentrations of this magnitude are not expected to occur in the Basin provided the TOSCØ process is used. Sulfur dioxide production from processes other than

TOSCØ is estimated from one to ten times greater, and hydrocarbon production from other processes is estimated to be three to four orders of magnitude greater than the TOSCØ process. If schemes other than the TOSCØ process were to be used, a reassessment would be necessary with respect to total hydrocarbons and sulfur dioxide. No federal or state 24 hour standard exists for oxides of nitrogen. Production of these oxides is dependent upon combustion temperature and therefore is highly variable. Oxides of nitrogen and hydrocarbons may combine to form photochemical smog in the presence of sunlight. This could become a problem if other processes of oil extraction are used, but no standards have been developed pertaining to combinations of pollutants emitted into the atmosphere.

Calculated concentrations of particulates are somewhat misleading as a result of the initial assumption that pollutants are not removed from the atmosphere by deposition. No size distribution was provided in the emissions data and therefore the total amount was assumed to be suspended. This would not be the case in reality, but without size distributions, the amount suspended cannot be reliably estimated. With this limitation disregarded, the Colorado non-designated area standard for particulates of $45 \mu\text{g m}^{-3}$ would limit the production of oil to a daily rate of approximately 68 thousand barrels under conditions of a 305 meter mixing depth which persists for 24 hours. The federal primary standard for particulates ($260 \mu\text{g m}^{-3}$) would allow a daily production rate of nearly 400,000 barrels. The federal secondary 24 hour standards, however, would limit the amount to less than 230,000 barrels per day.

As the mixing depth approaches the maximum elevations of the Piceance Creek Basin, more of the contaminated air becomes entrained into the synoptic flow and the production rate of oil shale facilities could increase to very high values without violating established ambient air quality standards within the Basin. Pollutants from the maximum feasible development, however, will have an unknown impact upon the environment beyond the Piceance Creek Basin.

SUMMARY

Even though data are severely limited or nonexistent, it is nevertheless reasonable to conclude that high potential for air pollution episodes exist in the Piceance Creek Basin of western Colorado. It is much more difficult to reach conclusions regarding the actual impact on air quality to be expected from proposed development of the oil shale industry. This difficulty is related to uncertainties in predicting which of the retorting techniques are to be used, in addition to the broad range of estimates of the size and number of facilities

TABLE 1. FEDERAL AIR QUALITY STANDARDS

Units are in $\mu\text{g m}^{-3}$.

Substance	Federal air quality standard	
	Primary	Secondary
<u>Particulate</u>		
annual geometric mean	75	60
24 hour maximum*	260	150
<u>Sulfur oxides</u>		
annual arithmetic mean	80	--
24 hour maximum*	365	--
3 hour maximum*	--	1300
<u>Oxidant</u>		
1 hour maximum*	160	160
<u>Hydrocarbons</u>		
3 hour maximum* (from 6 to 9 A.M.)	160	160
<u>Carbon monoxide</u>		
8 hour maximum*	10,000	10,000
1 hour maximum*	40,000	40,000
<u>Nitrogen oxides</u>		
annual arithmetic mean	100	100

*Not to be exceeded more than once per year.

TABLE 2. Colorado air quality standards. The Piceance Creek Basin is classified as a "non-designated area" and therefore the "designated area" standards are not applicable. Standards for oxidant, hydrocarbons, and carbon monoxide are shown even though these standards apply only to the Denver Air Quality Control Region as noted. There is currently no Colorado standard for nitrogen oxides. The standards shown in this table are currently subject to revision. Units are in $\mu\text{g m}^{-3}$.

Colorado Air Quality Standards				
Substance	Non-designated Area	Designated Area		
		1973	1976	1980
<u>Particulate</u>				
annual arithmetic mean	45	70	55	45
24 hour maximum*	150	200	180	150
<u>Sulfur oxides</u>				
annual arithmetic mean	-	60	25	10
24 hour maximum*	15	300	150	55
1 hour maximum*	-	800	300	-
<u>Proposed Denver Air Quality Control Region</u>				
<u>Oxidant</u>				
annual				
8 hour maximum*				
1 hour maximum*				
<u>Hydrocarbons</u>				
annual				
8 hour maximum*				
1 hour maximum*				
<u>Carbon monoxide</u>				
annual				
8 hour maximum*				
1 hour maximum*				

*Not to be exceeded more than once per year.

**Not to be exceeded more than once per month.

to be in operation in the near future. Further uncertainty is associated with the boundary conditions, assumptions, and extrapolations which may be violated or wrongly applied when using mathematical air pollution models. The limitations of this study, although many, are inherent in any attempt to determine the impact of projected industrial development upon the environment of a remote region before such development occurs. In the Piceance Creek Basin, under the assumptions that the TØSCØ process is used in facilities capable of producing 50 thousand barrels of oil per day, and assuming that the drainage winds are 2 m sec^{-1} beneath an inversion layer 305 meters (1000 feet) above the surface, the Colorado sulfur dioxide standard of $15 \mu\text{g m}^{-3}$ would be exceeded by 300 percent, while the federal standard of $365 \mu\text{g m}^{-3}$ would allow daily production of 400 thousand barrels. Under similar conditions, the federal secondary 24 hour particulate standard and the Colorado non-designated 24 hour particulate standard (both $150 \mu\text{g m}^{-3}$) would limit the daily oil production rate to less than 230 thousand barrels.

REFERENCES

- Colorado Air Pollution Control Regulations. Ambient Air Standards in Environment Reporter, State Air Laws, Section 326-0501. Bureau of National Affairs, Washington, D.C.
- Environmental Protection Agency. Regulations on national primary and secondary ambient air quality standards in Environment Reporter, Federal Regulations, Section 121:0101. Bureau of National Affairs, Washington, D.C.
- Hosler, C.R. 1961. Low-level inversion frequency in the contiguous United States. Monthly Weather Review 89(9): 319-339.
- Marlatt, W.E. 1973. Climate and air quality analysis of the Parachute Creek airshed, Garfield County, Colorado prepared for Colony Development Operations by Thorne Ecological Institute, Boulder, Colorado.
- Panofsky, H.A. 1969. Air pollution meteorology. Amer. Sci. 57(2): 269-285.
- Shaw, R.W. and R.E. Munn. 1971. Air pollution meteorology, p. 53-96, in McCormac, B.M. Introduction to the scientific study of atmospheric pollution. D. Reidel Publishing Company, Dordrecht, Holland.
- Turner, D.B. 1970. Workbook of atmospheric dispersion estimates. Environmental Protection Agency Office of Air Programs, Research Triangle Park, N.C. 84p.

An Air Quality Index to Aid in Determining Mountain Land Use¹

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Recently developed modeling techniques allow planners to incorporate air quality into land use plans early in the planning activity. A wind-field model was combined with dispersion models to determine a mixing volume. This mixing volume contains no source information, so planners would use a spatial matrix of the index as an input constraint in land use plans. Allowable emissions are calculated from the mixing volume index and the ambient air quality standards. These allowable emissions for each pollutant form an atmospheric constraint matrix for air pollution that is compatible with economic, social, and other models in land use planning.

INTRODUCTION

There has been a longstanding need to incorporate air quality constraints at an early stage in land-use planning activities. Traditionally, there has been no direct feedback or air quality information until after plans were somewhat formalized. Then, air quality would be evaluated as a residual calculation.

Non-degradation requirements set by the Environmental Protection Agency (Code of Federal Regulations 1975) require that all areas of the country be classified in areas in which no degradation is permitted (Class I), areas in which some degradation is permitted (Class II), and areas which allow air quality up to the primary standards (Class III). Because of these regulations, an air quality index that defines a carrying capacity or mixing volume of a geographic region, and permits preselection of desired air quality, is required. This air quality index should reflect only meteorological constraints. Emissions from planned activities could then be evaluated against this index to define projected air quality, or conversely if desired

air quality is to be predefined, the index could be used to determine the intensity and kinds of development, in terms of allowable emissions.

THE PLANNING INDEX

The Pollutant Standards Index (PSI or Ψ) has been proposed (Thom and Ott 1976) as a universal air quality index that facilitates comparison of air quality levels at different locations, and provides policymakers with a uniform measure for evaluating impact of regulations. The Pollution Standards Index is defined as a segmented linear function, where an index value of 100 is air quality at the Primary National Ambient Air Quality Standard, and an index of 50 is at the secondary standard, if a secondary standard exists. If no secondary standard is defined, then an index of 50 is half the primary standard. While the primary standards are set on the basis of human health, the secondary standards are designed to protect welfare, specifically to protect vegetation and materials. The PSI is defined as:

$$\Psi = a + b \frac{\chi}{\chi_s} \quad (1)$$

Where χ is the ambient concentration,
 χ_s is the primary standard, and

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the coefficients a and b are 0 and 100 respectively for SO_x, NO_x, CO and hydrocarbons.

For particulates, a = 0 and b = 87 for concentrations up to the secondary standard and a = -19 and b = 119 for concentrations between the secondary and primary standards.

Pollutant Standards Index values greater than 100 are not of interest to planners since these values exceed the National Ambient Air Quality Standards.

The actual concentration, χ , can be estimated from dispersion models. For simplicity, consider the mixing volume index as defined by the Gaussian dispersion model for complex terrain (Fosberg, et al. 1976). The concentration, χ in $\mu\text{g}/\text{m}^3$, is given by

$$\chi(x) = \frac{Q}{u} G(x) \quad (2)$$

where

Q = emission rate in $\mu\text{g}/\text{sec}$

u = mean velocity in m/sec

$G(x) =$

$$\frac{1}{\sqrt{2\pi} \sigma_y \sigma_z} \exp \left[-\frac{1}{2} \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2} \right] \exp(-\delta \Delta \tau)$$

where

$\sigma_y = \sigma_y(x)$ is the standard deviation of y of the pollution cloud in the lateral direction determined by Pasquill-Gifford curves (Turner 1969) (m)

$\sigma_z = \sigma_z(x)$ is diffusion in the vertical (m)

δ = mass divergence of the airshed in sec^{-1}

$\Delta \tau$ is the time increment over which the divergence acts (sec).

A mixing volume index can be defined from this formulation as

$$I = \frac{\chi}{Q} 10^6 = \frac{G(x)}{u} 10^6 \quad (3)$$

The scaling factor, 10^6 , was chosen by considering Turner's (1969) maximum value of $\chi u/Q$ for a ground level source with class F stability. This scaling gives a maximum index value of 1000, although the index values will typically be one or two orders of magnitude smaller. The index, I , contains only climatological information and has the advantage that it can be mapped over broad areas so that the planner need not be concerned with detailed dispersion processes.

A land use planning index can be formed by combining the Pollution Standards Index, Ψ , (eq. 1) with the Mixing Volume Index, I , (eq. 3).

The ambient concentration is eliminated between the two equations, with the result that

$$\frac{QI}{10^6} = \frac{(\Psi - a) \chi_s}{b} \quad (4)$$

Rearranging eq. 4 to solve for Q , a Pollution Index (PI or π) is formed which defines the maximum allowable emission in terms of mixing conditions, air quality standards and the nondegradation classification. The PI is simply the total allowable emission given as,

$$PI = Q = \frac{(\Psi - a) \chi_s 10^6}{b I} \quad (5)$$

The emission term Q can be generalized to include multiple sources of a given pollutant through

$$\sum_i n_i Q_i = PI \quad (6)$$

where n_i is the number of sources for a particular activity and Q_i is the emission rate for that activity.

The emission used in eq. (1) must be uniform in order for the Gaussian solution to be correct. Strictly the index (eq. 3) can be used to describe concentrations that result from a uniform emission. This is most appropriate for short times (one to three hours), where u does not vary substantially nor do the stability classes needed to determine the σ_y and σ_z values.

For longer times (24 hours) however, it is more appropriate to base concentration in a mountain valley complex on the concept of a box model. The total mass of pollution is assumed to be emitted into a volume described by an area of limited horizontal extent, topped by a low inversion. This type of calculation can be made using the index defined in eq. (3) if the Gaussian is evaluated at a downwind distance X_L sufficiently large that the cross-sectioned area approximates a valley cross-section. Details of this derivation are found in a companion paper (Fosberg and Fox 1976) which provides the theoretical development of these concepts.

The PI index for a box model is written as,

$$PI = \sum_i n_i Q_i \Delta t_i = \frac{9(\Psi - a) X_L \chi_s 10^6}{2 b I u} \quad (7)$$

Where again X_L represents the distance at which the concentration distribution approximately fills the appropriate cross-section.

A LAND USE PLANNING EXAMPLE

In order to illustrate how this technique would work in practice, we will use a wind field determined from a model of the wind over complex terrain (Fosberg, Marlatt and Krupnak 1976) and calculate the mixing volume index for each 3 km square grid cell. As a less involved method of calculating, I could employ data such as Holzworth's mixing depths (Holzworth 1972) and topography maps to estimate volumes. Mixing volume index values developed from either approach contain only information on dispersion potential.

For the purpose of this example we will use the wind field shown in figure 1. The area depicted in this example is in southwestern Montana. Meteorological conditions are chosen to be those which could lead to a high pollution period during a summer evening. As a specific example, consider the development of a 26,700 acre mountain subdivision. Our analysis is based upon 12 3 km square grid cells which cover the area. The primary sources of pollution will be fireplaces and automobiles. We assume that the State has classified the subdivision within an air quality maintenance area having a Class II designation. Particulate concentration in a Class II area cannot exceed $30 \mu\text{g}/\text{m}^3$ in a 24-hour period, or a $\Psi = 11$. Using the box model version of the Pollution Index, we solve eq. 7 to determine the number of fireplaces that can burn simultaneously,

$$PI = \frac{\sum_{i=1}^n n_i Q_i \Delta t}{2 b I u} = \frac{(\Psi - a) \chi_s 9 X_L 10^6}{2 b I u}$$

where

$$\Psi = 11$$

$$a = 0$$

$$\chi_s = 260 \text{ g/m}^3$$

$$X_L = 3000 \text{ meters}$$

$$b = 87, \text{ and}$$

I and u are determined for each cell from the flow field (u) and eq. 3, the mixing volume index.

The number of fireplaces or homesites with fireplaces is then

$$n = \frac{PI}{Q \Delta t}$$

We assume that fireplaces are burning for two hours ($\Delta t = 2 \text{ hr.}$) and the emission, $Q = 7.5 \times 10^7 \mu\text{g/hr.}$ is given by a recent EPA report (Snowden 1976). The number of fireplaces, n, in this tract is calculated for each of the 12 cells. Number of homesites per cell range from a low of 17 to a high of 50 giving a total of 441 for the entire tract. Thus the proposed subdivision must allot an average of 60 acres for each homesite. If the area were allowed to reach the National Ambient Air Quality

Standards, 3970 homesites of 6 acres each could have been developed. This average acreage includes common and non-developable property such as roads, parks, lakes, and so forth. Using similar procedures we could include emissions of CO, and calculate the allowable number of vehicles. It should be emphasized here that these calculations are for episode situations and not for typical meteorological conditions.

SUMMARY

The Pollutant Standards Index and the mixing volume index provide land planners with quantitative estimates of the number and type of emissions permitted in an area. The Pollutant Standards Index provides for a uniform interpretation of land use regulations while the mixing volume index relates these regulations to any meteorological limitations. The procedure allows the calculation of instantaneous pollution concentration using the Gaussian model concept (eq. 5) as well as the calculation of long term pollution, or pollution from intermittent sources using the box model (eq. 7).

The mixing volume index and the Pollutant Index provide planners with quantitative estimates of the allowable number of emission sources in a mountain valley. They allow the planner to quantitatively determine the mix of and amount of different activities contributing a particular pollutant to the air shed. Thus they provide the carrying capacity of the air shed for pollution and can be incorporated into other forms of planning models for general use.

REFERENCES

- Code of Federal Regulations.
- 1975. Title 30, Chap. 1, Part S2, p. 98-99.
- Epstein, A.H.
- 1974. A guide for considering air quality in urban planning EPA-450/3-74-020.
- Fosberg, M.A., W.E. Marlatt and L. Krupnak
- 1976. Estimating airflow patterns over complex terrain. USDA Res. Pap. No. 162, 16 p.
- Fosberg, M.A., D.G. Fox, E.A. Howard, and J. Cohen. 1976. Nonturbulent dispersion processes in complex terrain. Atmos. Env. 10:
- Fosberg, M.A. and D.G. Fox
- 1976. A topographic air pollution analysis system. submitted Atmos. Env.

Holzworth, G. C.

1972. Mixing depths, wind speed and potential for urban air pollution throughout the contiguous United States. U.S. Env. Prot. Agency Publ. No. AP-101.

Snowden, W. D.

1976. Report for EPA Contract No. 68-02-1992 by Valentine, Fisher and Tomlinson, Consulting Engineers, Seattle, Wash.

Thom, G. C. and W. R. Ott.

1976. A proposed uniform air pollution index. Atmos. Env. 10:261-264.

Turner, D. B.

1970. Workbook of atmospheric dispersion estimates. Env. Prot. Agency, 84 p.

Session VII
Influence of Atmospheric Pollutants on Biological Systems

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Forest Environment Research Staff
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The Changing Chemistry of Precipitation and Its Implications for Forest Growth and Productivity¹

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Abstract.--The nutrient status, growth and reproduction of plants on land and in surface waters is influenced by the availability of beneficial nutrient elements and potentially injurious substances dispersed in the atmosphere. In recent decades, human activities have greatly increased total emissions and deposition of substances from the atmosphere. A network of precipitation-measuring stations has existed in Europe since 1947 and has provided much insight into atmospheric chemistry and the effects of atmospheric trace constituents within terrestrial and aquatic ecosystems. The chemistry of precipitation also has been studied in certain parts of the United States and Canada. The results of these studies are described together with plans for development of a coordinated network to measure changes in the chemistry of atmospheric deposition and its effects on vegetation and surface waters in the United States and Canada.

ESSENTIAL ELEMENTS FOR GROWTH OF FOREST TREES

Fifteen elements are essential for the growth of forest trees (Table 1). Previously, it was believed that these elements were obtained almost entirely from the soil solution after release from decomposing organic matter, weathering of soil minerals, or addition as fertilizers. Now, it is recognized that air-borne gases, particulate matter, and aerosols significantly augment the supply of both essential elements (Tamm, 1958) and potentially injurious substances (Wood, 1968; Mudd and Kozlowski, 1975). Furthermore, all of the 15 essential elements listed in Table 1 can be taken up through foliar organs as well as by absorption from the soil solution (Wittwer and Bukovac, 1969).

Table 1.--Essential elements for growth of forest trees

Elements	Distribution	Availability
Carbon	All organic compounds	Rarely
Hydrogen	esp. cellulose, hemicelluloses and lignin	limiting
Nitrogen	Proteins, amino acids, nucleic acids, etc.	Usually limiting
Phosphorus	Nucleic acids, ATP, phospholipids, etc.	Often limiting
Potassium	Growing portions	Often limiting
Sulfur	Proteins	Sometimes limiting
Ca, Mg	Pectic substances	Rarely limiting
Fe, Cu,	Cofactors or constituents of enzymes or	Rarely limiting
Mn, Mo,		
Bo, Zn	cytochromes	

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Table 2 lists the major inputs and losses of nutrients from a forest ecosystem. Rennie (1955) has shown that much larger amounts of essential nutrients are required for sustained-yield agriculture than for sustained yield hardwood or softwood forestry. This is true because the part of trees that usually is harvested -- the wood and bark of the tree stem -- contain very much less of most essential elements than the seeds and other plant parts that are commonly harvested in agriculture. This is a

major reason why fertilization is so commonly practiced in agriculture but is much less common in forestry. In some forested regions, atmospheric deposition alone is more than adequate to permit harvesting of crop after crop of trees without fertilizing the forest.

Table 2.--Nutrient flux in a forest ecosystem

Addition of nutrients	Loss of nutrients
1) Precipitation	1) Air-borne pollen and spores
2) Salt spray from oceans	2) Harvesting of forest products
3) Wind-borne dust, soil particles, aerosols	3) Leaching from forest soils to ground water
4) Atmospheric gases: CO_2 , NH_4OH , N_2 , SO_2	

SOURCES AND AMOUNTS OF ATMOSPHERIC DEPOSITION

In recent decades, human activities have greatly increased total emissions and deposition of substances from the atmosphere (Oden, 1968, 1976) (Bolin, et al 1971). This is due mainly to increases in: 1) combustion of fossil fuels in industrial enterprises, residential heating, transportation, and agricultural operations; 2) use of fertilizers and other chemicals in intensive agriculture; and 3) decomposition of industrial, urban, and agricultural wastes. Previously, it was believed that most of these materials were removed from the atmosphere near the site of emission. Now it is recognized that atmospheric processes can lead to extensive mixing, and both chemical and physical interactions and transformations of atmospheric particles, aerosols and gases. Furthermore, these substances and their reaction products are dispersed by meteorological processes and finally enter the biosphere in fields of deposition that may extend hundreds or even thousands of kilometers from the original sources of emission. The recent fallout of radioactive substances in the eastern United States as a result of atomic explosions in the Peoples Republic of China provides a dramatic reminder of long-distance transport and deposition of pollutants. Thus, the chemical composition of atmospheric deposition within a given region is a function of all the airborne substances dispersed, mixed, transformed, and transported into the atmosphere of that region and then deposited in terrestrial and aquatic ecosystems (Dovland et al, 1976).

Forest, agricultural, and aquatic biologists are becoming increasingly concerned about atmospheric transport and deposition of both nutritionally beneficial and potentially injurious

substances. This is true because: 1) vegetation, soils, and surface waters are the primary deposition sites for precipitation and airborne particulate matter of all types; 2) atmospheric deposition constitutes an important source of nutrients and potentially injurious substances that effect the productivity and stability of these ecosystems; and 3) human activities are steadily increasing the amounts and variety of substances present in atmospheric deposition.

The amounts of various substances introduced deliberately or inadvertently by man into the biosphere of the earth are becoming so large that man is becoming a major force in the biogeochemistry of the earth (Kovda, 1975). This is shown in Table 3 which contains a tabulation of data on annual output of fertilizers, industrial dusts, garbage and other urban wastes and by products, mine refuse, and discharges of aerosols and gases. All of these categories of matter are becoming comparable in magnitude with the discharges of dissolved and suspended substances in all the rivers of the world, the annual yield of photosynthetic products, or the cycling of inorganic elements in the earth as a whole. Anthropogenic emissions into the atmosphere are also very large as shown in Table 4.

Table 3.--Biogeochemical and technological forces in the biosphere of the earth (data of Kovda, 1975)

Biosphere components	Tons per year
Biogeochemical processes:	
Yield of photomass	1×10^{10}
Cycle of inorganic elements	1×10^{10}
River discharges:	
Dissolved substances	3×10^9
Suspended substances	2×10^{10}
Anthropogenic sources:	
Output of fertilizers	3×10^8
Industrial dust	3×10^8
Garbage, urban wastes and byproducts	2×10^{10}
Mine refuse	5×10^9
Aerosols and gas discharges	1×10^9

Table 4.--Anthropogenic emissions into the atmosphere (data of Kovda, 1975)

Type of emission	Tons per year
Dust	2.5×10^8
Gases (mainly SO_2 , HC, and NO_x)	6.5×10^8
Carbon oxides ($\text{CO} + \text{CO}_2$)	2.0×10^9
Aerosols	1.0×10^9

Note: Doubling about every 7-10 years

If man is to so greatly augment the amounts of substance dispersed in the atmosphere and deposited into the biosphere of the earth, it is prudent (no essential!) that he should measure the amount and chemical form of the deposited matter and understand the biological consequences of that deposition. Regretably, our understanding of these processes in North America is fragmentary. Fortunately, however, more extensive measurements of atmospheric deposition and its biological consequences have been made in Europe where an atmospheric chemical network has been maintained since the late 1940's.

THE ATMOSPHERIC CHEMICAL NETWORK IN EUROPE

The first regional Atmospheric Chemical Network began in Scandinavia and has gradually spread to include most of western Europe and parts of eastern Europe including Poland and the Soviet Union. The substances analyzed at most of these stations include the following major cations and anions: NH_4 , NO_3 , PO_4 , K, Ca, Mg, SO_4 , Na, Cl as well as pH, conductivity, and titratable acidity and alkalinity.

Fig. 1 shows some long-term trends in amounts of nitrate nitrogen deposited at five locations in Europe. It is obvious that the amount of this important fertilizer element in precipitation changed markedly (generally increased) during the 15 years between 1955 and 1970. Nitrate nitrogen helps plants grow. Thus, the nitrogen added in precipitation would be expected to increase yields of agricultural and forest crops.

But not all the substances in precipitation are beneficial. Long term trends also have been detected in amounts of sulfate and hydrogen ions. Fig. 2 shows the trend in pH in six specific locations in Norway and Sweden. These changes have been attributed to strong acids formed in the atmosphere, mainly from oxides of sulfur and nitrogen produced during combustion of fossil fuels (Bolin et al, 1971). At present about two-thirds of the total acidity in rain and snow in Scandinavia and the northeastern U.S. is due to sulfuric acid and most of the remainder is due to nitric acid (Likens et al, 1976; Dovland et al, 1976).

In interpreting the data of Figs. 1 and 2 it is important to recognize that precipitation formed in an atmosphere relatively free of natural or anthropogenic sources of nitrogen or sulfur oxides would be expected to have a pH of 5.5-6.0 (Likens and Bormann, 1974; Dovland et al, 1976). Since pH is a logarithmic scale, a change in hydrogen ion concentration from pH 6.0 to pH 4.5 means a 32-fold increase in acidity.

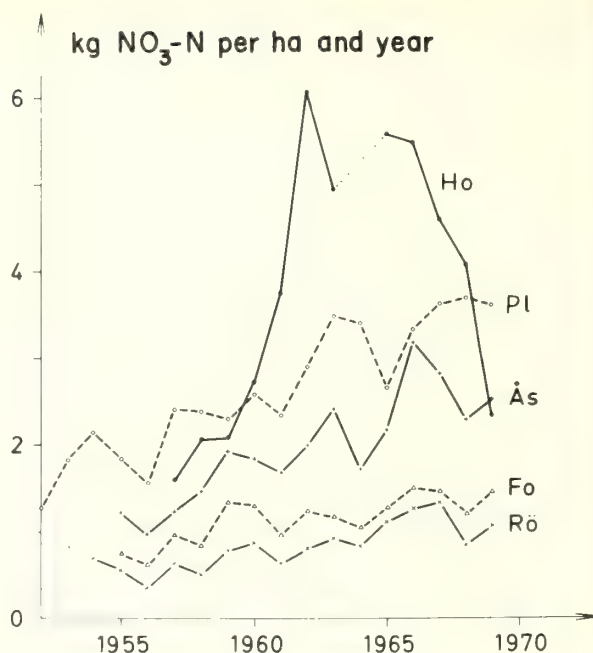


Figure 1.--Amount of nitrate nitrogen (1 kg/ha = about 1 pound/acre) deposited in precipitation at five locations in northern Europe during 1955-70. The station designated Ho is in West Germany, those designated Pl, Fo, and Rø are in Sweden, and the station designated Ås is in Norway. (Data of Oden, 1968).

PRECIPITATION CHEMISTRY IN THE UNITED STATES

Monitoring of the chemistry of precipitation also has been carried on in the United States (Feth et al, 1964; Lodge et al, 1968). Figure 3 shows some data that are typical of American monitoring studies: (1) The data were collected for a limited land area -- in this case parts of North Carolina and southeastern Virginia; and (2) the data were collected for a limited period of time (1962-63) (Gamble and Fisher, 1966). These data are very detailed and provide excellent and reliable information. But the study terminated in July 1963 and monitoring has not been done in the same area until very recently. The Hubbard Brook Experimental Forest in New Hampshire is the only site in the U.S. where the acidity of precipitation has been measured consistently for as long as 10 years.

Using measurements of precipitation chemistry in limited areas and periods of time, and assuming a stoichiometric balance between anions and cations in precipitation, Cogbill

and Likens (1974) calculated the probable average acidity of precipitation in the eastern United States.

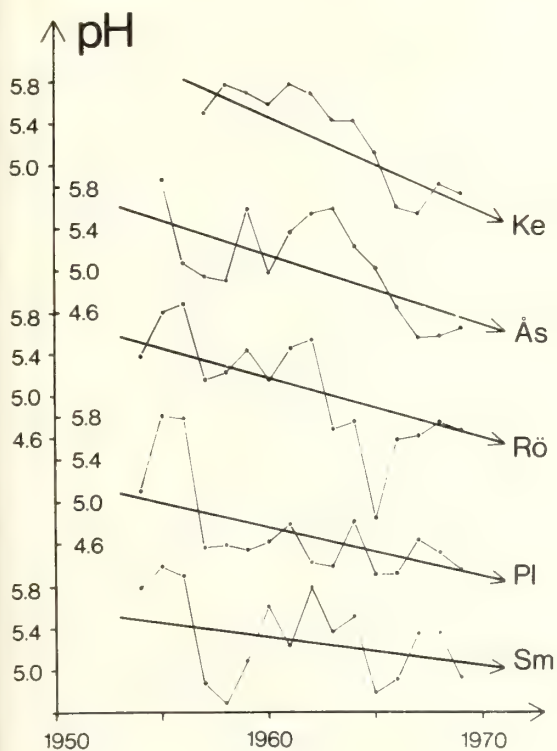


Figure 2.--Average acidity of precipitation collected at six locations in Scandinavia during 1965-79. The stations designated Ke and Ås are in Norway; those designated Rø, Pl and Sm are in Sweden. (Data of Oden, 1968).

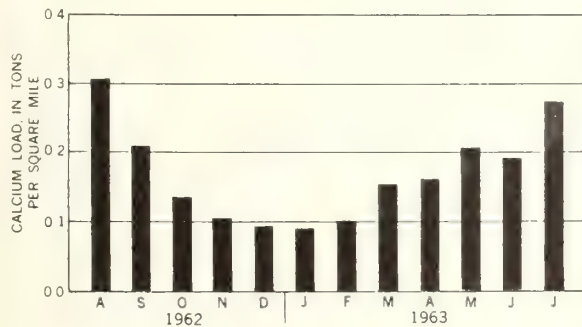


Figure 3.--Amount of calcium deposited in precipitation in parts of North Carolina and Virginia during 1962-63. (Data of Gambell and Fisher, 1966).

As shown in Figure 4 precipitation in a large portion of the eastern United States was less than pH 5.6 in 1955-56; the zone of greatest acidity (lowest pH) was generally consistent with the zone where sulfur emissions are high -- parts of Ohio, Pennsylvania, West Virginia, New York, and New England. By 1965-66, the zone with an estimated pH of 5.6 had continued to expand although the zone with a pH of less than 4.5 had not expanded greatly (Fig. 5). Note, however, that a new isopleth line of pH 4.4 is visible. By 1972-73, the area with an average pH of rain below 4.5 had extended to include parts of Mississippi, Alabama, Georgia, South Carolina, North Carolina, Kentucky, Virginia and further north into New England and Canada. Essentially, it embraces most of the area east of the Mississippi River (Fig. 6). Individual rainstorms with pH values between 2.1 and 3 have been reported in various locations -- in some cases many hundreds of kilometers from major sources of air pollution (Likens and Bormann, 1974).

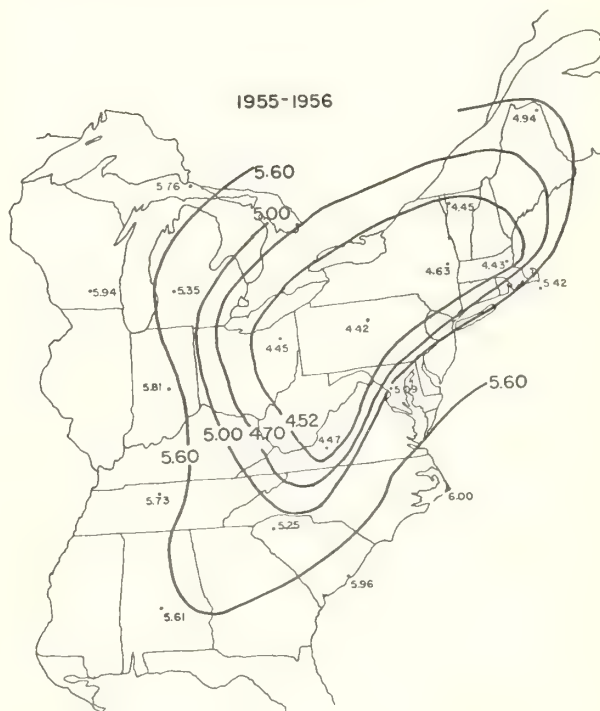


Figure 4.--Distribution of estimated acidity in precipitation in the eastern United States during 1955-56. (Data of Cogbill and Likens, 1974).

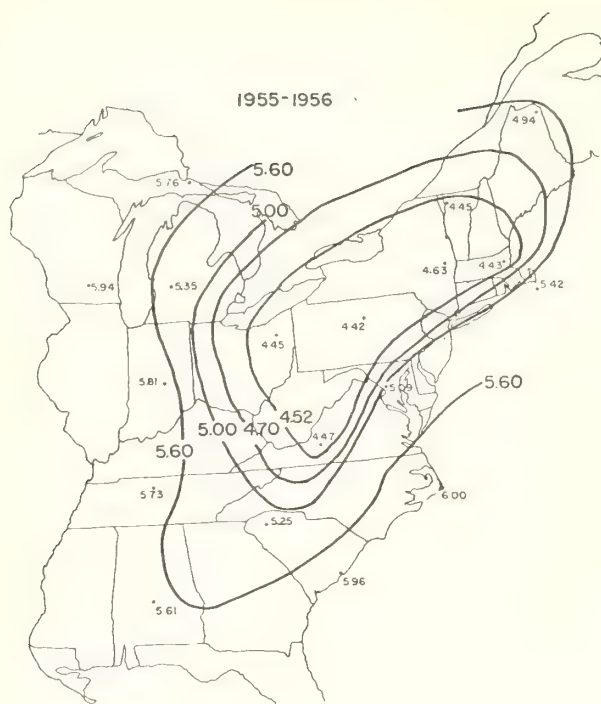


Figure 5.--Distribution of estimated acidity in precipitation in the eastern United States during 1965-66. (Data of Cogbill and Likens, 1974).

EFFECTS OF ACIDIC PRECIPITATION IN TERRESTRIAL AND AQUATIC ECOSYSTEMS

A great variety of effects of acidic precipitation on terrestrial and aquatic ecosystems were reported at two recent meetings: the First International Symposium on Acidic Precipitation and the Forest Ecosystem held at The Ohio State University in Columbus (Forest Service, 1976), and an International Conference on the Effects of Acid Precipitation sponsored by the Norwegian Ministry of the Environment held at Telemark, Norway (Braekke, 1976).

The most striking effects reported at these meetings were on populations of fish and other fresh water organisms (Giessing et al, 1976; Gorham, 1976). Dr. Carl Schofield (1976), an aquatic ecologist at Cornell University summarized these effects as follows:

"Rapid extinction rates of fish populations inhabiting acidified waters have been observed over the past few decades in the Scandinavian countries and parts of eastern North America. Documented case studies of several populations clearly indicate that extinction is often a result of

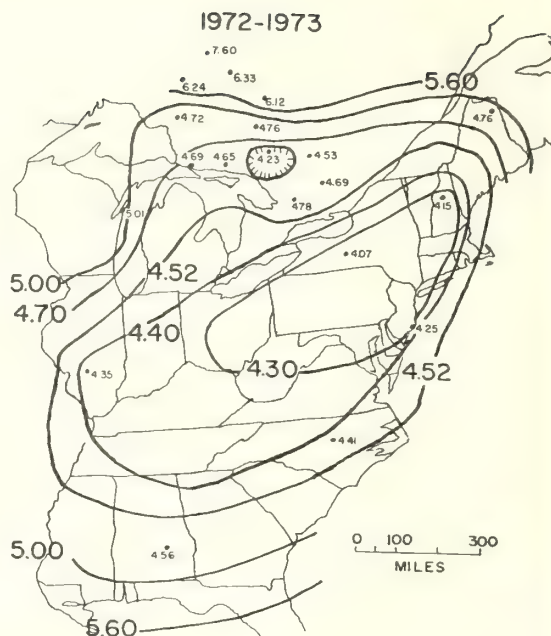


Figure 6.--Distribution of estimated acidity in precipitation in the eastern United States during 1972-73. (Data of Cogbill, 1975).

chronic reproductive failure due to acidification-induced effects on sensitive life-history stages."

Effects on soils and on forest vegetation generally have been less clear cut; but certain definite effects have been reported (Abrahamsen, et al 1976; Forest Service, 1976). The most striking of these was development of peat moss (*Sphagnum* sp.) as a submarine rather than a terrestrial plant in acidified lakes and streams in Sweden (Grahn et al, 1974). Dense mats of *Sphagnum* and an apparently parasitic aquatic fungus develop on the bottom of these lakes in water as deep as 18 meters. This growth induces oligotrophication (opposite of eutrophication) -- a self-accelerating process that leads to a substantial nutrient impoverishment of lake waters. Analyses of forest growth in southern Sweden from 1896 to 1965 showed a 2 to 7% decrease in growth between 1950 and 1965. Jonsson and Sundberg (1972) "found no good reason for attributing (this) reduction in growth to any cause other than acidification." Similar attempts to quantify possible effects on growth of forests in the United States have been inconclusive.

Other reports given at the meetings in Ohio and Norway indicate that: 1) forest canopies filter out sulfur and hydrogen ions from precipitation; 2) acidity of bark and development of cuticular features such as frequency and size of stomata can be used as biological indicators of acidification and sulfur pollution, respectively; 3) vegetation developing in recently formed sandy soils or glacial outwash areas is more vulnerable to the effects of acidic precipitation than vegetation growing in older, well-buffered soils of high clay content and consequently large base exchange capacity; 4) before reaching the soil, acidic substances in precipitation can induce direct changes in the physiology of foliar organs; 5) after reaching the soil, these substances also can induce changes in root function and the availability of essential cations; and 6) ammonia combines with sulfate ions in the atmosphere and tends to neutralize atmospheric acidity -- when the ammonia is absorbed by plants, however, both the ammonia and the released sulfate ions contribute to the total acidification of forest ecosystems.

Simulated "rain" acidified with sulfuric acid has been reported to: 1) induce direct injury to foliage of pines, birch and mosses; 2) induce symptoms similar to those caused by certain other pollutants and biotic pathogens; 3) induce poorer germination of spruce seeds; 4) accelerate leaching of nutrients from foliage of various angiosperms; 5) increase erosion of epicuticular waxes on oak and bean leaves; 6) decrease uptake of nitrogen by endomycorrhize of sweetgum seedlings; 7) inhibit reproduction of root-knot nematodes; 8) inhibit development of bean rust and production of telia by the oak-leaf-rust fungus, Cronartium fusiforme; 9) inhibit or stimulate development of halo blight in bean seedlings depending on the time in the disease cycle during which the simulated "rain" was applied; and 10) inhibit nodulation and fixation of nitrogen by Rhizobium in bean and soybean seedlings (Shriner, 1976).

Some differences of opinion about the effects of acidification also have become evident. These concern such matters as: 1) the pH of rain formed in a "clean" atmosphere; 2) the balance between nutritionally beneficial and injurious influences of sulfur and nitrogen compounds in precipitation; and 3) the likelihood of negative influences on growth of plants in well-buffered soils.

The possible economic consequences of the various biological effects listed above are not known. Nevertheless, the variety of biological influences that have been observed suggests that: 1) a network to measure long-term

changes in the chemistry of air and precipitation is needed in rural and urban areas throughout North America; and 2) much more research is needed to evaluate the ecological and possible economic influences of changes in the acidity and other chemical properties of precipitation.

THE NEED FOR AN ATMOSPHERIC CHEMICAL NETWORK IN NORTH AMERICA

As indicated above, the chemistry of atmospheric deposition has been measured in certain parts of the United States and Canada. But the sampling stations usually have been concentrated in localized regions or have been so relatively few-and-far between that regional and temporal trends have been difficult to discern. When intensive sampling has been accomplished, the data have been collected over relatively short periods of time.

The U. S. Geological Survey (USGS), the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the International Biological Program (IBP), the U. S. Environmental Protection Agency (USEPA), and the Canadian Atmospheric Environment Service (CAES) all have established deposition-measuring systems from time to time. But each of these systems has been relatively short lived. The latest efforts are by the CAES and by the USEPA in cooperation with NOAA. The latter two agencies established a national network which include the 10 U. S. sites of the World Meteorological Organization (WMO). The U. S. joined the WMO Network in 1972. None of the 17 sampling stations included in the U. S. network includes a calibrated watershed where precipitation data has been collected in the past. Furthermore, the collector currently being used is of a type which has been found least satisfactory among more than 12 different designs tested for NOAA (Galloway and Likens, 1975) (Berry et al, 1975).

The relatively short life of atmospheric chemical networks in the United States contrasts markedly with the longevity of the European Atmospheric Chemical Network. The success of the European network has been attributed to five major factors: 1) simplicity in the design of the deposition collector and the shipping and measuring systems; 2) low cost of the central analytical laboratory; 3) coordination of all phases of network operation by a dedicated group of scientists who concerned themselves with all aspects of network operation from choosing the collection sites to final interpretation and publication of the results; 4) continuity in sample collection; this was assured primarily by personal contacts among

scientists who were committed to discovering changes in the chemistry of atmospheric deposition and their ecological effects; and 5) availability of the data to all scientists who wished to use the data.

During the past year, a major cooperative effort involving many different agencies in the United States and Canada has been made to develop a more adequate, long-term regional or national network. The initiative for this effort has been taken by personnel of the State Agricultural Experiment Stations of the Cooperative State Research Service and the Forest Service within the U. S. Department of Agriculture. Other agencies which have indicated an interest in this endeavor include the Agricultural Research Service (ARS), the U. S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the Energy Research and Development Administration (ERDA), the Environment Protection Agency (EPA), the Canada Atmospheric Environment Service (CAES), the Canada Monitoring and Surveys Division (CMSD), the Sulfate Regional Experiment (SURE) of the Electric Power Research Institute (EPRI), the Tennessee Valley Authority (TVA), and other federal, state and private research institutes and universities in the United States and Canada.

A uniform set of collectors is planned for use at each collection site. Samples of precipitation and dry particulate matter will be collected at each site according to a specified schedule and shipped in specially provided containers to a central laboratory or regional analytical laboratories for analysis. During the establishment phase of network operation, most sample collections will be made on a regular schedule but selected stations will make collections on both a precipitation "event" (rain, snow, hail or dust storm) and a timed-sampled basis. Precautions will be taken to preclude changes in, or contamination of the samples during collection and transport prior to analysis. Analyses will be performed as soon as possible after shipment.

During the initial phase, analyses will be made for as many as possible of the following elements, ions, or other properties of each sample: SO_4 , NO_3 , NH_4 , PO_4 , Cl, F, Br, K, Na, Ca, pH, total and free acidity or alkalinity, and electrical conductivity. Later, as analytical capacity and interest develop, certain additional elements and substances may be added including total P, Zn, Cu, Mo, Pb, B, Ni, Cd, V, Mn and organic acids. In addition, analyses could be made for other air-borne materials including various pesticides, asbestos fibers, and other substances. Automated systems of analysis will be used

wherever possible to keep analytical costs as low as is consistent with reliability and relevancy in the results.

Development of the Network is envisioned as an evolving process extending over several years. It will begin with a small number (20-25) of collection stations in a limited geographical area and a modest list (10-15) of chemical parameters. Later, as more knowledge is acquired, the Network will grow in geographical area and completeness in terms of chemical parameters. Over time, the Network data will also increase in value for testing of hypotheses about source-sink relationships for major pollutants, mechanisms of atmospheric deposition for particular elements, atmospheric transport and transformation processes, and relevancy to known biological and ecological effects of atmospheric deposition.

To ensure that the network data are of such high quality that they enjoy maximum credibility for a wide variety of fundamental-research and mission-oriented purposes, an Analytical Standards Committee of impartial experts will be appointed. This Committee will critically and firmly oversee the operation of the network and its analytical laboratory(ies), so as to control and certify the quality of the data.

All data obtained by the proposed network will be made available to all potential users as soon as possible after analyses are completed. Any portion or all of the data will be provided upon request for any purpose of analysis or interpretation by personnel of any cooperating agency, public or private, which may wish to use the data. A highly flexible computerized system will be used to provide the data in maximally useful form.

SUMMARY

The major purpose of this paper is to describe certain aspects of the changing chemistry of precipitation and its effects on forest vegetation and surface waters. The data presented emphasize the need for a network of precipitation measuring stations in the United States and Canada to provide information about changes in the deposition of beneficial nutrient elements as well as potentially injurious substances. Such information is needed to permit prudent management of anthropogenic emissions of atmospheric trace constituents and the aquatic and terrestrial ecosystems in which these emissions and their transformation products are deposited.

LITERATURE CITED

- Abrahamsen, G., K. Bjor, R. Horntvedt and B. Tveite.
1976. Effects of acid precipitation on coniferous forest. pp. 36-63. In F. N. Braekke, 1976.
- Berry, R. L., D. M. Welpdale, and H. A. Wiebe.
1975. An evaluation of collectors for precipitation sampling. Proc. World Meteorological Organization Expert Meeting on Wet and Dry Deposition. Downview, Ontario. In Press.
- Bolin, B., L. Granat, L. Ingelstam, M. Johansson, E. Mattsson, S. Oden, H. Rodhe, and C. O. Tamm. 1971. Air pollution across national boundaries. The impact of sulfur in air and precipitation. Sweden's case study for the United Nations Conference on the Human Environment. P. A. Norstedt and Sons, Stockholm, Sweden. 97 pp.
- Braekke, F. H.
1976. Impact of acid precipitation on forest and freshwater ecosystems in Norway. Research Report FR6/76. SNSF Project, Ås, Norway. 111 p.
- Cogbill, C. V. and G. E. Likens.
1974. Acid precipitation in northeastern United States. Water Resources Research 10:1133-1137.
- Cowling, E. B., A. S. Heagle and W. W. Heck.
1975. The changing chemistry of precipitation. Phytopathology News 9(10):5.
- Dovland, H., E. Joranger and A. Semb.
1976. Deposition of air pollutants in Norway. pp. 14-35. In F. H. Braekke, 1976.
- Feth, J. H., S. M. Rogers and C. E. Roberson.
1964. Chemical composition of snow in the northern Sierra Nevada and other areas. U. S. Geol. Survey Water Supply Paper 1535-J. 39 pp.
- Forest Service. 1976. Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem. USDA Forest Service General Technical Report NE-23, Northeastern Forest Experiment Station, Upper Darby, Pa. 1974 pp.
- Galloway, J. N., and G. E. Likens.
1976. Calibration of collection procedures for the determination of precipitation chemistry. pp. 137-156 In Forest Service, 1976.
- Gambell, A. W. and D. W. Fisher.
1966. Chemical composition of rainfall, eastern North Carolina and southeastern Virginia. U. S. Geological Survey Water Supply Paper 1535-K. 41 pp.
- Glessing, E. T., A. Henriksen, M. Johannessen, and R. Wright. 1976. Effects of acid precipitation on freshwater chemistry. pp. 64-85. In F. H. Braekke, 1976.
- Gorham, E.
1976. Acid precipitation and its influence upon aquatic ecosystems -- an overview. pp. 425-458. In Forest Service, 1976.
- Grahn, O., H. Hultberg and L. Landner.
1974. Oligotrophication - a self-accelerating process in lakes subjected to excessive supply of acid substances. Ambio 3:93-94.
- Jonsson, B. and R. Sundberg.
1972. Has the acidification by atmospheric pollution caused a growth reduction in Swedish forests? Research Note No. 20. Department of Forest Yield Research, Royal College of Forestry, Stockholm, Sweden. 48 pp.
- Kovda, V. A.
1975. Biogeochemical cycles in nature, their disturbance and study. Faculty of Pedology, Moscow State University, Moscow, USSR. In Press.
- Likens, G. E. and F. H. Bormann.
1974. Acid rain: a serious regional environmental problem. Science 184:1176-1179.
- Likens, G. E., F. H. Bormann, J. S. Eaton, R. S. Pierce, and N. M. Johnson.
1976. Hydrogen ion input to the Hubbard Brook Experimental Forest, New Hampshire during the last decade. pp. 397-407. In Forest Service, 1976.
- Lodge, J. P., J. B. Pate, W. Basbergill, G. S. Swanson, K. C. Hill, E. Lorange and A. L. Lazrus.
1968. Chemistry of United States precipitation. Final report on the National Precipitation Sampling Network. National Center for Atmospheric Research, Boulder, Colorado. 66 pp.
- Mudd, J. B., and T. T. Kozlowski.
1975. Responses of plants to air pollution. Academic Press, New York. 392 pp.
- Oden, S.
1968. The acidification of air and precipitation and its consequences in the natural environment. Ecology Committee Bulletin No. 1. The State National Science Research Council, Stockholm. Translation Consultants, Ltd., Arlington, Virginia. 117 pp.
- Oden, S.
1976. The acidity problem -- an outline of concepts. pp. 1-36. In Forest Service, 1976.
- Rennie, P. J.
1955. The uptake of nutrients of mature forest growth. Plant and Soil 7:49-95.
- Scofield, C. L.
1976. Effects of acid precipitation on fish. Proceedings International Conference on Effects of Acid Precipitation, Telemark, Norway. In Press.
- Shriner, D. S.
1976. Effects of simulated rain acidified with sulfuric acid on host-parasite interactions. pp. 919-925. In Forest Service, 1976.

Tamm, C. O.

1958. The atmosphere. Handbuch für
Pflanzenphysiologie 6:233-242.

Tamm, C. O., and E. B. Cowling.

1976. Acidic precipitation and forest
vegetation. pp. 845-855. In Forest
Service, 1976.

Wittwer, S. H. and M. J. Bukovac.

1969. The uptake of nutrients through leaf
surfaces. pp. 235-261. Scharrer and H.
Linser, Eds. Handbuch der Pflanzenernährung
und Düngung. Springer-Verlag, New York.

Wood, F. A.

1968. Sources of plant-pathogenic air
pollutants. Phytopathology 58:1075-1084.

Plant-Pollutant Interactions and the Oak Ridge Approach to Air-Pollutant Impact Analysis¹

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Abstract.--The processes by which pollutants move from the atmosphere to sites of action within plant cells are influenced by a wide variety of physical, chemical and biological factors. Of major importance among these are the physical and chemical form of the pollutants, the kinetics of the pollutant exposure regime, the solubility of pollutants in cell systems, and their biological reactivity. The impact of a given dose on plant response is mediated by the above factors as well as many plant-related variables. Present needs in air pollution research relative to interactions of these factors are discussed with special emphasis on chronic impacts of potential regional scale significance.

INTRODUCTION

Although the phytotoxic effects of air pollutants have been recognized for over 100 years, scientists are still challenged by many unanswered questions in efforts to accurately assess air pollutant impacts on vegetation. The problem stems partly from the innate complexity of chemical, physical and biological processes through which plants and pollutants interact, and partly from the fact that the questions themselves are changing.

The purpose of this discussion is first to highlight some of the major factors involved in air pollutant impact analysis, and second, to describe some of the studies under way at ORNL which we hope will reduce some of the uncertainties involved in those analyses.

These studies include investigations of the transport, fate, and biological effects of

both gaseous pollutants and particulate contaminants. Major emphasis will be placed on studies involving gaseous pollutants with individual projects ranging in scope from detailed physiological studies designed to consider short-term changes in growth-related processes to regional scale analyses designed to examine impacts on large temporal and spatial scales. The rationale behind these investigations will serve to stress what we see as primary challenges of both the present and the future in the area of plant-pollutant interactions.

The study of air pollution impacts on vegetation is, in simplest terms, a study of dose and response. The major challenge of air pollution researchers in both the field and in the laboratory is determining what doses and responses are significant in terms of developing a capacity to predict ultimate impacts in real world situations. How do we characterize dose so that it reflects the potential for phytotoxic effects, and what processes do we measure to determine whether an adverse response has occurred?

Consideration of Pollutant Dose

Averaging Interval

As a product of two continuous variables, concentration and time, dose may be described

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in an infinite number of ways. Normally, gaseous pollutant exposures are characterized as concentration averages over some time interval. The time interval chosen, however, is quite critical in determining the consistency with which the average will describe phytotoxic potential. Figure 1, for example, indicates four obviously different ways in which an exposure equal to the current secondary ambient air quality standard for SO_2 (e.g., 3h avg = 0.50 ppm) may occur. This same total dose may have widely varying peak concentrations, short-term averages, and pollutant-free intervals. The selection of a biologically meaningful averaging interval is related to the biochemical and physiological processes involved with pollutant uptake and activity in living cells. Since plant leaf tissues appear to have a limited potential for oxidizing the very toxic sulfite ion (formed initially when SO_2 is dissolved in cell liquids) to the less toxic sulfate form, the short-term averages may be quite critical in determining ultimate damage at the cellular level. Based on extensive field studies in Germany, Stratmann (1963) has suggested that averaging intervals of 15 minutes may be more appropriate for describing phytotoxic potential of SO_2 . More definitive studies are needed to ascertain this, however.

Exposure Frequency

Another potentially important consideration of dose, which is not reflected by short-term averages, is the frequency of exposure of vegetation throughout the growing season. While physiological processes such as photosynthesis may show only temporary suppression in response to single exposures in the laboratory, the response of photosynthetic processes after repeated exposures, such as may occur in the field, has not been assessed. Present EPA air quality standards reflect the current emphasis on single episodes which may produce visible injury and ignore the frequency of lower levels which may produce chronic stress at cellular or biochemical levels.

Pollutant Combinations

An additional consideration in dose description is the occurrence of multiple exposures involving more than one pollutant. Pollutants normally occur in the field in combination, and there is increasing evidence to indicate that pollutants may interact in modifying plant responses (see review by Reinert et al. 1975). Effects produced by pollutant combinations have

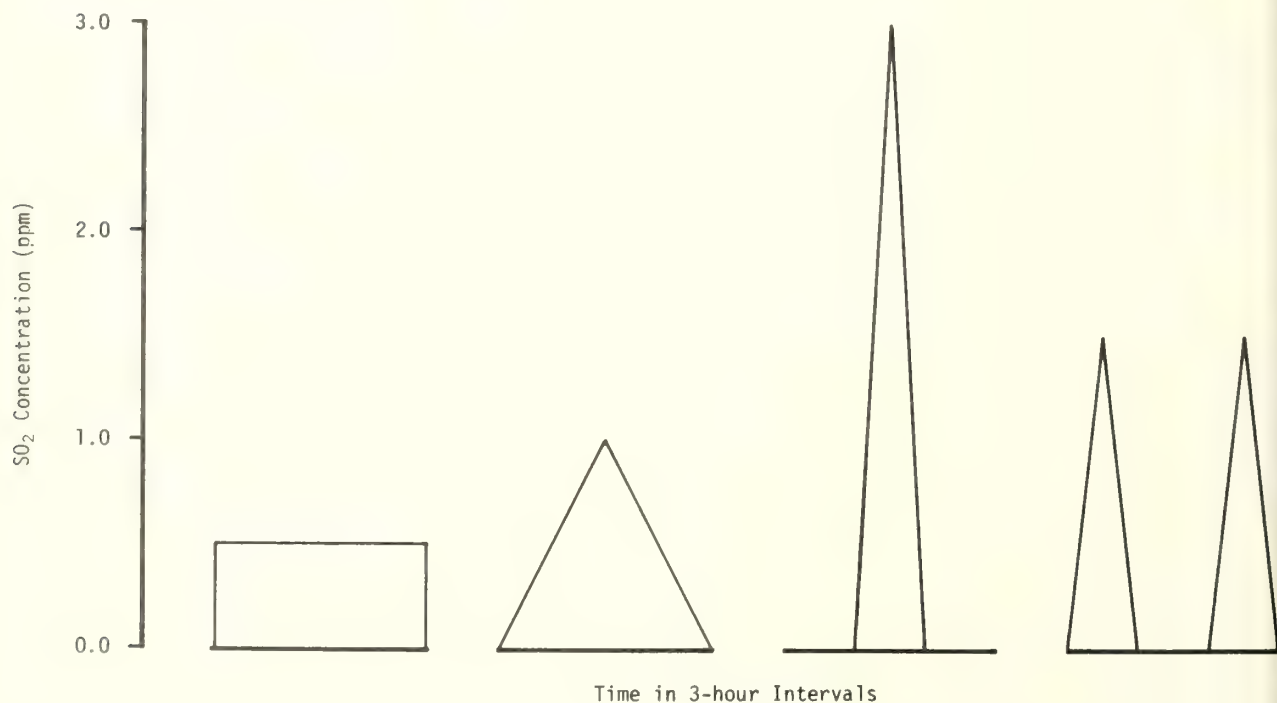


FIG. 1. SOME POSSIBLE OCCURRENCES OF A 3 HOUR AVERAGE SO_2 CONCENTRATION EQUAL TO 0.5 PPM.

been shown to be antagonistic, additive, or synergistic depending on the process studied and the relative concentrations of pollutants involved. Most of the data have been accumulated in laboratory experiments involving mixtures of SO₂ and O₃ or SO₂ and NO₂. The occurrence of additive effects on plant growth following chronic exposure to very low levels of SO₂ and O₃ (0.05 ppm/ 0.05 ppm) in some studies (Tingey et al. 1971) indicates that pollutant combinations may well be significant in regional scale impacts on terrestrial plant ecosystems. Such evidence also indicates that multiple exposures should be considered an important component in studies designed to consider pollutant dose.

Additional Considerations

While the external concentrations of pollutants to which plants are exposed are critical in determining the likelihood of a response, it is the quantity and form of pollutant which reaches the metabolically active tissues which determines whether a response will occur. As primary absorbing organs, leaves and roots are particularly susceptible tissues. Important factors determining the quantity of a pollutant reaching these tissues are its solubility in cellular fluids, its inherent biochemical reactivity, and the ease with which it is detoxified or eliminated by plant cells. Additional variables influencing the impact of a pollution episode are the environmental conditions before and after exposures and the phenological stage of the plant at the time it is exposed.

Plant Response to Pollutants

Responses of plants to air pollutants may be categorized both in terms of the type of effect produced (e.g., foliar injury, reduced growth or reproduction, increased morbidity, mortality) and the time scale (acute or chronic) over which these effects occur. With increased control of atmospheric emissions we may expect a shift in importance of these responses toward more subtle changes produced over longer time periods. While localized acute effects still occur around some point sources, the advent of tall stacks and emission controls can be expected to reduce these impacts to minor proportions. Potentially more significant are chronic impacts resulting from regional scale enhancement of pollutant burdens.

Types of Chronic Impacts

Due to differences in modes of occurrence, sites of action, and the facility with which

biological systems can metabolize individual pollutants, chronic air pollution effects on vegetation may occur in a variety of ways. Initial definition of the characteristics of the pollutant exposure regime is extremely critical to a thorough understanding of the types of effects that may be produced and the temporal scale on which they may occur. Exposure regimes that produce chronic low-level effects may result from repeated episodic exposures to concentrations just below the level required for visible damage, or from long-term accumulation of toxic materials absorbed at low levels from the edaphic or atmospheric environment. Three major types of responses may result from chronic air pollutant insults to individual organisms; reduced growth, altered reproduction, and increased morbidity (Smith 1974). Collectively, these responses form the basis for concern for larger scale alterations of ecosystem structure and stability. The responses, however, are evidences of more fundamental impacts of pollutants on basic physiological processes upon which living systems depend. Characterization of the physiological basis of these effects improves our understanding of the mechanisms of toxicity and thereby facilitates the evaluation of probable risk to environmental systems from projected levels in the atmospheric or edaphic environment.

Experimental Approaches to Plant-Level Effects

Probable mechanisms and pollutants potentially responsible for reduced growth, reduced reproduction and increased morbidity, are shown in Table 1. Pollutants included with each process are those for which specific effects have been documented and those whose biochemical symptomology strongly implicate them as probable causal agents. The wide range of processes listed in this table accentuates another problem facing plant researchers, the choice of a suitable plant response. Much of our concern for chronic low-level effects of air pollutants stems from indications that growth of plants may be affected at levels of pollutants below those associated with visible injury to foliage. The diverse responses listed in Table 1 indicate that ultimate growth effects may result from a general deterioration of cellular processes. Many of these process level effects, however, may be secondary reactions resulting from changes in membrane permeability accompanied by a loss of essential levels of subcellular organization and control. Nevertheless, the variety of physiological processes affected indicates that there is a very high potential for very subtle physiological changes which may be accentuated in the presence of stresses which occur naturally in the field.

Table 1.--Types of chronic low-level effects and probable mechanisms involved

Type of effect	Probable mechanisms	Pollutants involved ¹
Reduced growth	Decreased photosynthesis	SO ₂ , O ₃ , NO _x , HF, PAN, Pb
	Increased respiration	HF, SO ₂
	Biochemical changes	
	Enzyme inhibition	SO ₂ , O ₃ , PAN, HF, As
	Electron (energy) transport	HF, O ₃ , PAN
	Effects on photopigments	SO ₂ , HF, O ₃ , PAN, NO _x
	Stomatal function	SO ₂ , O ₃
	Membrane permeability	O ₃ , PAN, SO ₂ , HF, metals
	Premature senescence of leaves	SO ₂ , O ₃ , PAN, NO ₂
	Physical changes	
	UV reflectivity	Acid rain
	Heat exchange	Acid rain
	Gas exchange	Acid rain
	Changes in symbiosis	O ₃ , acid rain
	Effects on nutrient flux	SO ₂ , acid rain
Reduced reproduction	Reduced carbohydrate availability for reproductive structures	SO ₂ , O ₃ , HF, PAN, Pb, NO ₂
	Effects on reproductive processes	
	Flower or fruit production	Smog, HF, SO ₂
	Pollen germination or tube elongation	SO ₂ , O ₃ , HF
	Mutagenesis	SO ₂
	Effects on pollinating insects	HF
Increased morbidity	Inadequate carbohydrate supply to support autotrophic respiration and resist disease. Reduced growth and loss of ability to compete with other vegetation	SO ₂ , O ₃ , HF, PAN, NO ₂ , heavy metals

¹Includes pollutants for which specific effects have been documented and those whose biochemical symptomology strongly implicate them as probable causal agents.

While detailed biochemical and cytological studies have provided researchers with a considerable body of data (Zeigler 1973; Mudd and Kozlowski 1975) to indicate the potential damages of air pollution stress, changes in growth, reproduction, or morbidity represent the final integration of underlying physiological processes. Quantification of plant-level effects on these processes under field conditions, however, is quite difficult because of the difficulties of separating pollution effects from those of the many other variables which also affect these processes.

A particularly promising technique for examining plant responses to pollutants in the field involves the use of charcoal-filtered chambers to exclude pollutants from the air supplied to test plots (Heagle et al. 1973;

Mandl et al. 1973). Comparisons of growth and yields of crop plants grown under these conditions with those at adjoining plots grown in ambient air have been used to assess pollutant impacts of soybeans both in the East where plants were exposed to regionally elevated levels of gaseous pollutants (Howell, R. H., personal communication), and near point source emissions of SO₂ from a fossil fuel power plant in Alabama (McLaughlin 1974). In both experiments, yields were reduced by approximately 30% in ambient air compared to those attained in charcoal-purified air. While this approach appears promising as an assessment tool, there are still some questions about possible physiological changes which may enhance the sensitivity of plants grown in chambers of this type. These are being investigated by researchers presently and answers should be forthcoming.

Even more difficult to quantify than organismic responses are those which may occur at the ecosystem level. These may be classified as changes in overall productivity, system diversity, or system stability. Evidence for these types of changes has come mainly from studies around point sources where distance-related gradients have been examined (see review by Miller and McBride 1975). The changes generally follow a well-recognized stress response pattern (Woodwell 1971) where tolerant species known as "generalists" replace the more advanced (i.e., complex) seral stages of forest succession.

Evidence of changes of this type over large areas currently impacted by chronic air pollution are relatively rare in the literature, primarily because such changes are chronic in nature and necessitate long-term studies of a type rarely conducted. There is already evidence, however, that certain species such as lichens (Hawksworth and Rose 1974) and white pine (Ellertsen et al. 1970) may be eliminated or reduced in response to regional increases of pollutants, primarily sulfur oxides. Although changes in structure or diversity of whole ecosystems due to low-level air pollutant effects can be expected to initially be gradual and very subtle in nature, Treshow (1968) has stressed that ecosystems are delicately balanced systems and their structure may depend on a relatively few matrix species. The process of environmental deterioration may be slow, but once natural balances are sufficiently disrupted, subsequent alterations may be more precipitous due to more rapid irreversible changes. The incidence of disease for example may be greatly accelerated as plants are gradually weakened to the point where disease resistance is lowered.

Changes in ecosystem stability may also result from direct effects of pollutants on soil and soil microorganisms (Treshow 1968). The effects of acid rain on both soil and soil microorganisms represent a very real regional-scale stress on these systems. Low-level inputs of relatively immobile trace metals may also, over a long period of time, further stress microbial or soil systems to produce subtle regional-scale impacts of the type already being recognized in close proximity to smelting operations. While many of these low-level effects can currently only be deduced from extrapolation of our present practical experience with somewhat higher levels, our concerns should be real. They point to a drastic need for more research in the area of chronic low-level impacts.

While we are still coping with some of the old questions, additional questions are being posed with the development of new technologies. Having learned from past examples of "after-thought technology," decision-makers very justifiably would like biological research and engineering technology to be interfaced as soon as is practical while the technologies are being developed. An example is the developing coal conversion technology designed to produce clean burning, low-sulfur synthetic fuel oils and natural gas (Richmond et al. 1976). The processes currently being developed involve hydrogenation of coal under high pressure and temperature. The reducing atmosphere of these processes may release a variety of inorganic and organic effluents to the atmosphere which have not been associated with coal combustion (at least in comparable quantities), and consequently have been studied very little or not at all. These effluents include reduced sulfur and nitrogen compounds, and a wide variety of aliphatic and aromatic hydrocarbons. Very little is currently known about the persistence, toxicity and ultimate fate of many of these compounds in aquatic or terrestrial ecosystems. There is a clear need for research to provide a basis for making decisions regarding coal conversion technology which serve both economic and environmental objectives.

The preceding discussion has stressed some of the more important considerations which air pollution researchers must address in quantifying potentially significant interactions between plants and pollutants. The following overview of selected research efforts in progress at Oak Ridge National Laboratory illustrates some approaches being taken in our air pollution research programs.

Ongoing Air Pollution Research Programs at Oak Ridge National Laboratory (ORNL)

A. Ecological Effects of Coal Combustion: Response of Vegetation to SO₂, O₃, and Acid Precipitation

This project is examining plant physiological responses to three pollutants which are either associated with, derived from, or interact with atmospheric emission from coal combustion. It encompasses a series of laboratory and greenhouse studies emphasizing the determination of critical aspects of dose and plant response to SO₂, O₃, and acid precipitation. Results of these studies will be used to determine the type and level of responses to be expected as a result of exposure of plants to subacute levels of these pollutants. With

pollutant dose, primary emphasis is being placed on achieving exposure levels and kinetics which will closely approximate those occurring under field conditions. Exposure kinetics are being varied with SO₂ to consider the effects of peak and short-term average concentrations, repeated exposures, and exposure history. Ozone will eventually be added concurrently to determine the significance of interactions in modifying responses noted with SO₂ alone. With acid rain experiments, initial emphasis is being placed on determining the range of responses produced by rather high (pH 3.2) levels of acidity in simulated rainfall. Ultimate experimental designs will vary acidity levels both between and within rainfall events and exposure frequency to determine critical dosage characteristics. The possible role of acid precipitation in sensitizing plants to SO₂ and O₃ will also be examined. Principal plant responses being measured include photosynthesis, respiration, water use efficiency, and growth. Initial studies are being conducted with kidney beans with eventual experimentation to include seedlings of yellow poplar, white oak, short-leaf pine, and loblolly pine.

B. Effects of Coal Conversion Effluents on Vegetation

The development of coal conversion technologies has raised questions regarding potential environmental problems resulting from a variety of potentially toxic organic and inorganic byproducts. Our program in coal conversion effects at ORNL has developed in response to these questions and represents an effort to provide an "environmental feedback loop" to development of the technology by identifying at an early stage principal toxic components of atmospheric effluents from the process. The approach being taken involves near-term laboratory exposures of plants to gases representative of major classes of compounds with expected phytotoxicity. Eventual testing will include exposures involving gaseous mixtures collected from an experimental coal conversion facility being developed at the Laboratory and at planned pilot and demonstration plants being developed through ERDA/ industrial cooperative agreements. Gaseous compounds which are being utilized include hydrogen sulfide, carbonyl sulfide, carbon disulfide, phenol, carbon monoxide, methane, ethylene, benzene, and xylene. Experiments are designed to determine exposure levels required for both acute and chronic toxicity of individual compounds and mixtures. Data derived from these studies will be utilized to determine both the types and levels of control required to minimize effects of coal conversion effluents on terrestrial vegetation.

C. Interactions of Air-Borne Contaminants with Forest Systems

Air pollutants enter the biogeochemical cycles of forested landscapes by the processes of wetfall and dryfall, or in litterfall following deposition on and/or uptake by foliage. ORNL is currently involved in a number of programs aimed at quantifying mechanisms of input, subsequent biogeochemical fate, and biological effects of air-borne contaminants on forest systems. Studies of the type described below are being used in a number of ways including validation of air transport models, identification of net fluxes and sites and rates of accumulation of contaminants in forest systems, and quantification of mechanisms of biological impact on ecosystem processes.

(1) Wet and dry deposition of particulate contaminants on a forested watershed. These studies involve investigation of the mechanisms regulating inputs of contaminants by wetfall and dryfall processes including the role of canopy scavenging in element cycles. Elemental inputs are being monitored by a series of 6 wetfall, throughfall, and settled particulate collectors distributed throughout the 97.5 ha Walker Branch Watershed research site at Oak Ridge. In addition, periodic sampling of foliage from selected species of trees at several locations has been carried out during the past growing season to determine chemical speciation and relative amounts of various contaminants retained on foliar surfaces. Major emphasis is on deposition of Cd, Pb, Zn, Mn, and SO₄ to leaf surfaces. Preliminary analyses indicate that processes of deposition and impaction have conventionally been greatly underestimated and that these processes augment dryfall deposition to levels much above those expected from ground level dryfall measurements.

(2) Biogeochemical fate of pollutants in forest systems. Watershed studies of nutrient fluxes through forest systems have played a key role in ORNL's involvement in ecosystem analysis research during the past 5 years (Curlin 1970; Henderson and Harris 1975). Sampling and analytical techniques employed in quantification of nutrient fluxes have recently been utilized to describe biogeochemical cycling of contaminants through the forested Walker Branch Watershed (Andren et al. 1975; Van Hook et al. 1976). These studies have been aimed at determining the distribution of contaminants in vegetative and soil profiles and the rates and sites of accumulation of these contaminants in components of biogeochemical cycles. While the distribution and cycling of Cd, Pb, and Zn have been determined (Van Hook et al. 1976), the recently derived budget for sulfur (Shriner and Henderson, in preparation) is of particular interest in view of present concern over regional-scale

loading of terrestrial systems with sulfur derived from fossil fuel combustion. Present analyses indicate an annual input of $18.8 \text{ kg ha}^{-1} \text{ yr}^{-1}$ with an annual accumulation of $7.5 \text{ kg ha}^{-1} \text{ yr}^{-1}$ for Walker Branch. Of this total, approximately 59% is accumulated in the mineral soil with the remainder in the biomass pools of the vegetation and litter components. These studies are continuing in efforts to follow and project long-term changes in forest ecosystem response from regional sulfur loading.

(3) Monitoring biological response of forests to heavy metal contamination. Experience in systems analysis based on Walker Branch studies was recently applied to investigations of the effects of a lead smelter on forests of the Crooked Creek Watershed in southeastern Missouri (Watson 1976). These studies were designed to determine the fate of heavy metals (primarily Pb, Zn, Cd, and Cu) deposited on the forested landscape and the effects of these metals on various ecosystem components. The greatest accumulation in biological components occurred in the forest floor litter where inhibition of microbial decomposition occurred. Metals remineralized from the litter layer were leached into the soil where active uptake by plant roots occurred. Ecosystem level effects documented in this study include: (1) accumulation of incompletely decomposed deciduous litter, (2) decreased microbial activity out to 2 km from the stack, and (3) depressed macronutrient pools out to 0.8 km. Evidence collected to date indicates that a disruption of normal nutrient cycling processes has occurred. The areal extent of these effects may increase with continued deposition of heavy metals and can be expected to eventually result in decreased productivity of the impacted forests.

D. Modeling Pollutant Transport

An air transport model (Mills and Reeves 1973; Culkowski and Patterson 1976) which was jointly developed by researchers at ORNL and the NOAA Atmospheric Turbulence and Diffusion Laboratory at Oak Ridge, currently provides a capability for describing the distribution of atmospheric pollutants around sources of a variety of types. This type of information will be quite important in ultimate efforts to interface dose-response information with levels of pollutants to be expected over vegetated landscapes. The ATM is a Gaussian plume model developed to predict atmospheric concentrations of air pollutants at distances ranging from 0.1 to 50 km from point, area, or line sources. Operation of the model requires basic information on the physical characteristics of the source(s), source strength and diffusion coefficients of effluents of interest, and meteorological parameters (principally wind

direction and velocity, and temperature lapse rate). In addition to calculating concentration regimes of gaseous pollutants, the ATM has been coupled with the Wisconsin Hydrologic Transport Model (Patterson et al. 1974) to provide estimates of wetfall and dryfall deposition rates of aerosol constituents. An important flexibility of the ATM is the capability of predicting episodic concentrations of pollutants (including maximum groundline concentrations under adverse meteorological conditions) over time intervals as short as one hour. Longer distance transport may also be considered by coupling the ATM with the Trajectory Windrose Model of Heffter (1975). The ATM is currently finding applicability in a variety of research areas, including prediction of pollutant inputs to watersheds, estimation of the effects of industrial siting on regional air quality, and prediction of maximum groundline concentrations of airborne effluents from developing technologies. Such information is used in designing experiments to test probable toxicity of expected effluent concentrations.

E. Modeling the Response of Forest Systems to Air Pollution Stress

The patterns of growth and succession observed in developing forest systems may be considered to have resulted from interactions between the inherent potential of individual species to reproduce and grow initially at a site, and biotic and abiotic stresses subsequently experienced at that site. Among the abiotic stresses which have been speculated to cause long-term changes in forest systems is chronic exposure to air pollutants. A forest stand growth and succession model, FORET, developed at Oak Ridge by Shugart and West (1976) is currently being examined as a tool to project potential alterations in stand growth and composition as a result of stresses imposed by chronic levels of air pollutants. The model was designed to simulate changes in growth and successional patterns of eastern forests. Validation of the model was performed by examining the response of forests to the removal of American chestnut by the chestnut blight. The model functions similarly to the forest growth model developed by Botkin et al. (1972). Growth of individual trees is simulated on 1/12 hectare sample plots for any specified species combination and simulation time desired. The model will be used to project probable impacts of pollutants on forest growth and succession by examining the differential effects of pollutants on various tree species. Data derived from past field and laboratory studies with trees are being used to determine relative sensitivity of different species. Tests will be run to determine both levels of effect and requisite time intervals for significantly altering forest growth and development.

Our overview of these projects has served to emphasize that air pollution impact analysis is a multifaceted task requiring an integration of efforts from activities in a variety of fields. Ultimate characterization of impacts on terrestrial ecosystems will require the combined efforts of effluent characterization, transport modeling, and characterization of biogeochemical fates, as well as the more commonly attempted dose-response studies conducted by plant scientists. While coupling these processes in an integrated assessment represents a significant challenge to air pollution researchers, the tremendous economic costs of both pollution control and the consequences of increased pollutant stress on terrestrial ecosystems demand that it be vigorously addressed.

LITERATURE CITED

- Andren, A. W., S. E. Lindberg, and L. C. Bates.
1975. Atmospheric input and geochemical cycling of selected trace elements in Walker Branch Watershed. ORNL/NSF/EATC-13. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Botkin, D. B., J. F. Janak, and J. R. Wallis.
1972. Some ecological consequences of a computer model of forest growth. *J. Ecol.* 60:849-873.
- Culkowski, W. M., and M. R. Patterson.
1976. A comprehensive atmospheric transport and diffusion model. ORNL/NSF/EATC-17. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Curlin, J. W.
1970. Models of the hydrologic cycle. pp. 268-285. IN D. E. Reichle (ed.), *Analysis of Temperate Forest Ecosystems*. Springer-Verlag, Berlin, Heidelberg, New York.
- Ellertson, B. W., C. J. Powell, and C. L. Massey.
1970. Report on study of diseased white pine in Tennessee. *Mitt. Forstl. Bundesversuchsanst., Wien* 97:195-206.
- Hawksworth, D. L., and F. Rose
1970. Qualitative scale for estimating sulfur dioxide air pollution in England and Wales using epiphytic lichens. *Nature (Lond.)* 227:145-148.
- Heagle, A. S., D. E. Body, and W. W. Heck.
1973. An open-top field chamber to assess the impact of air pollution on plants. *J. Environ. Quality*. 2:365-368.
- Heffter, J. L., A. D. Taylor, and G. J. Ferber.
1975. A regional-continental scale diffusion and dispersion model. NOAA-TM-ERL-ARL-50. Air Resources Lab., Silver Springs, Maryland.
- Mandl, R. H., L. H. Weinstein, D. C. McCune, and M. Keveny.
1973. A cylindrical, open-top chamber for the exposure of plants to air pollutants in the field. *J. Environ. Quality*. 2:371-376.
- McLaughlin, S. B.
1974. Results of 1973 field studies on the effects of atmospheric emissions from Widows Creek Steam Plant on crops. TVA Internal Report TI-EB-74-6. Tennessee Valley Authority.
- Miller, P. R., and J. R. McBride.
1975. Effects of Air Pollutants on Forests. pp. 195-235. IN Mudd, J. B., and T. T. Kozlowski (eds.), *Responses of Plants to Air Pollution*. Academic Press, New York.
- Mills, M. T., and M. Reeves.
1973. A multi-source atmospheric transport model for deposition of trace contaminants. ORNL/NSF/EATC-2. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Mudd, J. B., and T. T. Kozlowski.
1975. *Responses of Plants to Air Pollutants*. Academic Press, Inc., New York. 383 p.
- Patterson, M. R., J. K. Monroe, D. E. Fields, R. D. Ellison, A. A. Brooks, and D. D. Huff.
1974. A user's manual for the FORTRAN IV version of the Wisconsin Hydrologic Transport Model. ORNL/NSF/EATC-7. Oak Ridge National Laboratory, Oak Ridge, Tennessee.
- Reinert, R. A., A. S. Heagle, and W. W. Heck.
1975. Plant responses to pollutant combinations. pp. 159-177. IN Mudd, J. B., and T. T. Kozlowski (eds.), *Responses of Plants to Air Pollutants*. Academic Press, New York.
- Richmond, C. R., D. E. Reichle, and C. W. Gehrs.
1976. Balanced Program Plan: Vol. IV. Coal Conversion. ORNL-5123. 314 p.
- Shugart, H. H., and D. C. West.
1976. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight (submitted to *Ecology*).
- Smith, W. H.
1974. Air pollution effects on the structure and function of the temperate forest ecosystem. *Envir. Poll.* 6:111-129.
- Stratmann, H.
1963. "Freiland zur Ermittlung von Schwefeldioxidwirkungen auf die vegetation. II. Messung und Bewertung der SO₂-Immissionen." (Field experiments to determine the effects of SO₂ on vegetation. II. Measurement and evaluation of SO₂ groundlevel concentrations). *Forschungsberichte des Landes Nordrhein. Westfalen, Essen, W. Germany*. No. 1984. 69 p.
- Tingey, D. T., W. W. Heck, and R. A. Reinert.
1971. Effect of low concentrations of ozone and sulfur dioxide on foliage, growth, and yield of radish. *J. Amer. Soc. Hort. Sci.* 96:369-371.
- Treshow, M.
1968. Impact of air pollutants on plant populations. *Phytopath.* 58:1108-1113.

Van Hook, R. I., W. F. Harris, and G. S. Henderson.

1976. Cadmium, lead, and zinc distributions and cycling in a forested watershed. Submitted to Ambio.

Watson, A. P., R. I. Van Hook, D. R. Jackson, and D. E. Reichle.

1976. Impact of a lead mining-smelting complex on the forest-floor litter arthropod fauna in the New Lead Belt Region of Southeast Missouri. ORNL/NSF/EATC-30. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Ziegler, I.

1973. The effects of air polluting gases on plant metabolism. Environmental Quality and Safety 2:182-208.

Research Advances in Terrestrial Effects of Environmental Pollutants¹

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Abstract.--Research on the terrestrial effects of environmental pollution is presently evolving from the traditional static, single pollutant acute dose/response studies on selected individual plant and animal species to dynamic ecological investigations of multiple pollutants, chronic effects on complex terrestrial ecosystems, components and processes. Examples are discussed in the context of need for continued development and relevance to whole systems problems.

INTRODUCTION

Terrestrial ecology research supporting Federal environmental pollution control programs historically has been associated with air pollution legislation since 1955. Until 1973 the productivity of "welfare" effects research called for in the Clean Air Act of 1970 was related principally to the acute effects of individual "criteria" pollutants on specific crops, trees and other vegetation. This work, conducted cooperatively with the USDA, Agricultural Research Service and Forest Service, provided the scientific support for the establishment of national secondary air quality standards and other pollution control strategies. Continuing work with "criteria" and other gaseous pollutants is being directed toward more representative simulation of ambient pollution exposures which are characterized by stochastically (randomly) varying concentrations over time and pollutant mixes as they may occur in the real world. The effects of these exposures on selected crops and tree species are being measured in terms of reduced yield and/or marketability of the product to provide damage function information for economic loss analysis.

Recent recognition of the broader ecological implications of environmental pollution has

generated new initiatives in plant/soil process studies, including nutrient cycling, soil litter decomposition and nitrogen fixation. This work indicates a need for further in-depth research on the long term, chronic impact of single and mixed pollutants, including trace elements and heavy metals as well as end products of gaseous emission transformations (e.g., sulfates and acid precipitation). The entire matter of long term chronic effects on whole terrestrial ecosystem dynamics remains to be unraveled before any assurance of the adequacy of pollution control strategies can be assumed.

Other new EPA initiatives in terrestrial ecology research include a coal-fired power plant field study in eastern Montana to support the Federal energy program and a pesticide substitute-chemical project designed to develop methodologies for screening new candidate pesticides. In both these programs the scope of investigation ranges from single species effects to whole system components, including ecological niches and natural food chain dynamics.

Although existing legislation and present resources in terrestrial ecology effects research are still based on support for only single species dose/response studies, the following topics relating to basic physiological processes and broadened whole ecosystems problems illustrate the current evolution in air pollution effects research.

AMBIENT EXPOSURE SIMULATIONS

A valid and serious criticism of air pol-

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lution research on plants has been the poor relationship between experimental exposures (single pollutant, continuous, generally high concentrations in control chambers) and ambient exposures experienced by plants in the "real world." This shortcoming resulted in the rescinding of the long term (one year average) secondary air quality standard for sulfur dioxide in 1973.

Since that time, experimental methodologies have become more sophisticated. Controlled pollution doses have been made more realistic through application of stochastic modeling to air pollution surveillance data from key locations in the national monitoring network. Crop plants and tree species used in experimental studies now "see" randomly varying pollutant levels, concentration ranges and pollutant mixes which simulate real conditions at varying distances from point and non-point sources. Results from these studies provide new insight into the season-long growth effects and yield reductions associated with single and multiple pollutant exposures.

Another innovative approach is being field tested in eastern Montana. The Zonal Air Pollution System (ZAPS) provides a way to disperse controllable levels of gaseous pollutants over an area of up to one acre. This is accomplished, with minimal disturbance of the natural ground cover, through a system of pipes with appropriately spaced orifices suspended within two feet of ground level. Preliminary analysis of data for the first season of operation indicates good controllability of pollutant concentrations at ground level. Further testing and refinements may permit broader use of ZAPS for controlled exposure studies.

STRESS ETHYLENE

Ethylene is one of many volatile reactive hydrocarbons emitted as a byproduct of green plant metabolism. Preliminary investigations show that the ethylene production rate is a sensitive measure of plant physiological stress. Although the precise mechanism is not yet understood, concentrations of gaseous pollutants (ozone and SO₂) well below existing national standards cause measurable increases in ethylene emissions by selected plant species.

This phenomenon is being investigated to determine 1) whether elevated ethylene production levels can be correlated reliably with reduced crop and forest growth and 2) what contribution this and other reactive hydrocarbon gaseous emissions from vegetative cover may make to ambient background levels of photochemical oxidant precursors in rural and remote areas. Results of this work will provide a new

perspective for developing future regional air pollution control strategies.

NITROGEN FIXATION

Existing secondary air quality standards for photochemical oxidants and sulfur dioxide are related to the visible effects of these pollutants on plant foliage. Recent findings indicate that the process of nitrogen fixation in the rhizosphere of growing legumes and forest trees may be substantially impaired by pollution levels well below the present standards. Based on the importance of nitrogen fixation in the biosphere and the apparent sensitivity of this process to pollution stress, current plant and soil investigations over a wide range of environmental pollutants have incorporated nodulation and nitrogen measurements to reflect effects on nitrogen fixation.

These measurements are included in studies of such diverse problems as gaseous air pollutants, acid precipitation, trace elements, pesticides and solid waste. Nitrogen fixation may indeed be considered a "sentinel" process which can serve as a primary indicator of pollution-caused ecosystem stress.

SOIL LITTER DECOMPOSITION AND NUTRIENT CYCLING

The rate of natural conversion of forest litter to humus and recyclable nutrients is considered an indicator of forest productivity. Reductions in the soil litter decomposition process caused by environmental pollution stress may, therefore, impact the long term growth of selected tree species. The extent and significance of these relationships are being investigated in ongoing field and laboratory research which is addressing the problems of photochemical oxidants, sulfur dioxide, acid precipitation, and trace element/heavy metal pollution.

TOXIC SUBSTANCE UPTAKE AND TRANSLOCATION

Root, leaf and seed crop plants grown in treated soil of varying chemical and physical characteristics can be used to test uptake and bioaccumulation of introduced toxic substances, including trace elements and heavy metals commonly found in phosphate fertilizers, industrial waste and pesticide residues. Tests recently conducted at the EPA's Corvallis Environmental Research Laboratory showed uptake of cadmium, contained in phosphate fertilizers, by radish, lettuce and peas. Percentage of Cd in fertilizer recovered was 5.3, 9.0 and 2.0, respectively. The highest concentration recovered was over 6 µg/g dry weight in lettuce when

fertilized at the rate of 100 μg P/g soil with concentrated super phosphate containing 174 μg Cd/g fertilizer (.087 μg Cd/g soil).

CONCLUSIONS

Considerable development is underway in approach, techniques and scope of investigations

relating to terrestrial effects of environmental pollutants. Cooperation and involvement among a broader segment of ecologically based skills and disciplines will further enhance the advancement of knowledge in whole systems problems.

Natural Atmospheric Cleansing Processes¹

W. G. N. Slinn²/

Abstract.--Residence times for atmospheric trace constituents are defined and the separate contributions from wet and dry removal and from chemical transformations are displayed. Three methods are outlined for estimating wet removal's contribution to the residence time; dry transfer through the atmosphere and deposition to various surfaces are discussed. A number of worked examples demonstrate state-of-the-art estimates for atmospheric residence times of particles and gases and where future research is needed.

INTRODUCTION

When considering natural atmospheric cleansing processes it is convenient to distinguish, separately, wet and dry removal processes. Wet removal or precipitation scavenging proceeds via the incorporation of air pollutants into precipitation (rain, snow, hail, graupel, etc.) and the subsequent deposition of the pollutants at the earth's surface. As was seen in the paper by Cowling (this volume) this process can significantly influence the chemistry of the precipitation; in this paper, however, the emphasis will be on the role precipitation scavenging plays in cleansing the atmosphere. Dry removal or dry deposition proceeds without the aid of precipitation and, as was seen in the paper by McLaughlin and Shriner (this volume) plant-pollutant interactions can be a major factor in the efficiency of dry removal processes. Thus, for example, pollutant-plant interactions dictate relatively rapid dry removal of HTO or ¹⁴CO₂ and, in contrast, essentially zero removal of ⁸⁵Kr. Besides these pollutant-plant interactions, though, it is necessary to consider dry deposition of particles and gases to a variety of other surface types. Some general features of these topics will be presented here. Details about a third important "removal process", viz. chemical transformations in the atmosphere, will generally be avoided both because of my limited knowledge and because these transformations usually must be treated on an individual-

case basis.

It was requested that the general thrust of this presentation be aimed at defining problems and discussing possible solutions in the general area of air pollution removal processes. In my opinion, the main problem is to determine atmosphere residence times for pollutants. This problem is a subset of the general problem to determine health and environmental consequences of pollution releases. It is admittedly true that in many cases these consequences can be correlated directly with pollutant air concentrations or, in some cases, directly with local pollution releases. However, the importance of atmospheric cleansing processes becomes apparent when attempts are made to relate local air concentrations to distant sources; e.g., to relate sulfate concentrations in New York to sources in Pennsylvania, Ohio, or even in New Mexico. In cases such as these it is necessary to evaluate pollutant removal between sources and sinks. To summarize the rest of this presentation, my best "guesstimate" is that: for aerosol particles released in the troposphere, there is a distribution of residence times with mean value (approximately equal to the variance!) of about one week; for gases, the residence times can vary from a few hours or less for very reactive gases (whose "removal" is dictated by chemical transformation) to about 10⁷ years for helium. The main problems, then, are to increase the accuracy of these estimates and to explain their variability. In this presentation, the emphasis will be on how these residence times are estimated, what is the source of the variability, why there remain inaccuracies in the estimates, and where future studies could help reduce some of the uncertainties.

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RESIDENCE TIMES

As will be seen, there are a number of different ways to estimate atmospheric residence times. Incidentally, other names with which similar "residence times" are identified are "lifetimes", "turnover times", or sometimes, "e-fold times". One method to estimate pollutant lifetimes is similar to the usual estimator for human lifetimes: add the measured lifetimes of n humans and divide by n . However, it is essentially impossible to determine the lifetime of individual gas molecules or aerosol particles and it is difficult and/or expensive to mount substantial tracer experiments to obtain similar information. As an alternative, the average lifetime of a total of N people can also be determined if the population has reached a steady state with B , births = D , deaths per unit time interval. Then the average lifetime

$$T = N/B = N/D. \quad (1a)$$

Similarly, if a steady state has been reached between production P and removal R of an air pollutant, leading to a total quantity Q in the atmosphere, then the residence time is

$$T = Q/P = Q/R \quad (1b)$$

As an example of the use of (1), consider sulfur compounds in the atmosphere. Their average mixing ratio is about 1 ppbm and therefore, since the mass of the troposphere is 4×10^{21} g, $Q = 4$ Tg. Natural and anthropogenic sources sum to give $P = 200$ Tg yr^{-1} within a factor of about 2. Consequently, the lifetime of sulfur compounds in the troposphere, Q/P , is about one week. This estimate could already have important practical value: it would suggest that, indeed, SO_2 releases from, for example, the Four-Corners power plants could result in increases in sulfur concentrations on the east coast of the U.S. However, this estimate for the lifetime of sulfur compounds is not accurate, at least to within a factor of 2 and possibly to within as much as an order of magnitude.

To improve the accuracy of the residence time as given by (1), it is necessary to obtain more accurate and/or representative information about Q and either P or R . For pollutants with relatively short residence times and/or point sources, there can be great variability in the air concentrations and therefore in estimates for Q . For example, SO_2 concentrations in the U.S. meet and sometimes exceed the EPA primary standard of $365 \mu\text{g m}^{-3}$ (24-hr average) and yet, sometimes within a matter of hours, the SO_2 concentrations can fall to near background levels of a few $\mu\text{g m}^{-3}$. This variability, to a greater or

lesser extent, is a characteristic of all atmospheric trace constituents and reflects variations in air trajectories, removal processes and source strengths. Qualitatively, it is expected that the longer the pollutant's residence time the smaller would be the concentration variations (e.g., as measured by the coefficient of dispersion, f , which is the standard deviation divided by the mean) since the longer the residence time, the greater the opportunity for atmospheric turbulence to suppress fluctuations. Indeed, Junge (1974) recently proposed an ingenious semi-quantitative method to estimate residence times of pollutants of recent concern (e.g., the low molecular weight halogenated hydrocarbons) using the empirical result $T = 0.14 \text{ yr}/f$. However, even if Q is known reasonably accurately, inaccuracies in R and P can limit the accuracy of estimates for T based on (1). For example, Junge (1963) used fairly reliable estimates for the total precipitable water vapor in the troposphere in 10° latitude belts and divided these Q 's by annual average rainfall in each belt to obtain appropriate T values (typically about one week, with some latitude dependence). Nevertheless, as pointed out by Junge, these estimates can not be considered too reliable since steady state conditions rarely prevail and mixing between latitude belts was ignored. Further, though, perhaps all removal processes were not included since apparently much water vapor is removed to the oceans in the dynamic process of evaporation and condensation; if account is taken of this "dry deposition" of water vapor, the estimated residence times might necessarily be reduced to about 2/3 the values given by Junge. Alternatively, T can be estimated from Q/P but uncertainties can enter in estimates for P , especially if a substantial fraction of the "pollution" is actually from natural sources. For example, in the case of aerosol particles, certainly a major (but unknown) fraction of the global-averaged amount is of natural origin. In the case of sulfur compounds, it can be somewhat amusing to conclude from various estimates made during the past fifteen years, that the sulfur from natural H_2S sources has progressively fallen from 170 to 160 to 30 to 20×10^6 tons yr^{-1} ! In summary, then, many uncertainties enter into the use of (1) and consequently it is compelling to seek alternative methods for estimating atmospheric residence times; in particular, to develop quantitative understanding of the removal processes themselves.

WET REMOVAL

There are a number of ways to estimate wet removal's contribution to a pollutant's atmospheric residence time. Perhaps the simplest conceptually follows from assuming that the average fraction \bar{e} of pollution entering a

precipitating storm is scavenged by the storm. Further, let the average time between storm encounters be \bar{v}^{-1} . Then it is simple to deduce the estimate for the pollutant's residence time if only wet removal processes are acting:

$$\tau_w = (\bar{v} \bar{v})^{-1} \quad (2)$$

If it is further assumed that precipitating events form a stochastic Poisson process then familiar results can be used to deduce the probability of any number of scavenging events in a given time period. As an example of the use of (2), if for particles $\bar{v} = .25$ and if $\bar{v} = (2.5d)^{-1}$ then $\tau_w \approx 10$ d. At present, however, the practical value of (2) is severely restricted because of almost total lack of information about \bar{v} and \bar{v} . Notice that the average storm frequency \bar{v} is actually in a Langragian sense, moving with an air "parcel". Conceivably, \bar{v} could be estimated from global circulation models but, to the author's knowledge, this task has not been undertaken. Also, if the average fraction of pollutant removed per storm \bar{v} is written as

$$\bar{v} = \bar{v}_1 \bar{v}_{cw}$$

where \bar{v}_1 is the average fraction of pollution entering the cloud water and \bar{v}_{cw} is the average efficiency with which storms precipitate cloud water, then the unsolved meteorological problem of estimating cloud water removal efficiencies becomes apparent. Presumably this can vary from essentially zero to perhaps as much as 90%. Thus, in summary, although τ_w as given by (2) is simple in principle, lack of knowledge severely restricts its practical value.

A method for estimating τ_w which has considerably more practical value relies on a widening data base for washout ratios. The washout ratio r is the ratio of the pollutant's concentration in precipitation to its concentration in surface level air: $r = (\kappa/\chi)_0$. From a recent tabulation of measured ratios (Slinn et al, 1977) it is seen that for trace metal aerosol particles typically $0.1 \lesssim r \lesssim 0.5 \times 10^6$ (dimensionless). Similar values have also been obtained for the reactive gases NH_3 , NO_2 , and SO_2 where, in these cases, the ratios are of the reaction product mass concentration in rain to the precursor-gas mass concentration in surface level air. A semiquantitative analysis by Junge (1963) demonstrates the reasonableness of aerosol particle and reactive gas washout ratios near 10^6 . Thus, if the average fraction \bar{v}_1 of the pollutant entering a storm is incorporated into cloud water, then the concentration of the captured pollutant is $\bar{v}_1(\chi)$ units per volume or $\bar{v}_1(\chi)/(L)$ units per mass of cloud water, where χ is the pollutant's

air concentration, L is the condensed water content of the cloud and the braces, $\{ \}$, represent an average over the storm. If this concentration $\bar{v}_1(\chi)/(L)$ also appears in the precipitation from the storm (which would be true for gravitational coagulation of equally polluted drops and for no evaporation or dilution enroute to the earth's surface) then the volumetric concentration in surface level precipitation, χ_0 , would be $\bar{v}_1 \rho_w(\chi)/(L)$. With $(\chi)/\chi_0 \approx 1$, $\rho_w = 1 \text{ g cm}^{-3}$, $(L) \approx 10^{-6} \text{ g cm}^{-3}$ then this gives $r = (\kappa/\chi)_0 \approx \bar{v}_1 10^6$. Recently, Junge (1975a) reviewed estimates for \bar{v}_1 which include nucleation and Brownian attachment of particles to cloud particles and from this review it can be concluded that values in the range $0.1 \lesssim \bar{v}_1 \lesssim 1$ are quite to be expected. For gases which form simple solutions in cloud water, then an adequate approximation is to set $\kappa_0 = H^{-1} \chi_0 = \alpha \chi_0$ where H is (one form of) Henry's law constant and $\alpha = H^{-1}$ is the solubility coefficient; therefore, in this case, $r = \alpha$. Using tables of solubility coefficients (e.g., Slinn et al, 1977) it is found that the washout of such gases is generally ignorable. Given the washout ratio, the wet flux is $W = r p_0 \chi_0$ where p_0 is the surface level precipitation rate, or the wet deposition velocity, W/χ_0 , is $v_w = r p_0$. For example, with $r = 0.3 \times 10^6$ and $p_0 = 100 \text{ cm yr}^{-1}$, then the annual-average wet deposition velocity would be $v_w \approx 1 \text{ cm s}^{-1}$. Consequently, a simple mass balance in a volume of the atmosphere of scale height $h_w = \int \chi dz / \chi_0$ from which pollution is removed by wet processes, gives

$$\tau_w = h_w / v_w = h_w / (r p_0). \quad (3)$$

For example, if $h_w = 10 \text{ km}$ and $v_w \approx 1 \text{ cm s}^{-1}$ then $\tau_w \approx 10$ days. To improve the accuracy of (3), h_w would be useful to increase the data base of washout ratios and it is essential to obtain some firm information about h_w .

A third way to estimate wet removal's contribution to a pollutant's atmospheric residence time depends on detailed considerations of collision processes and transfer rates to arrive at formulations for rain, snow, etc. scavenging rates, Ψ . However, space limitations recommend against describing details here (see, e.g., Slinn 1976a,b). In outline, for the case of rain scavenging of particles, it is first necessary to consider various processes (e.g., inertial impaction, interception, Brownian diffusion, and various phoretic processes) which are responsible for the collision between an individual particle and a raindrop. Then integrations are performed over all drop sizes and, if a particle mass-average scavenging rate is desired, over all particle sizes. When a number of approximations are introduced the result is

$$\tau_w = \Psi_r^{-1} = [c p E(a, R_m) / R_m]^{-1} \quad (4)$$

and a similar result for snow scavenging. As an example of the use of (4), for $c = 0.5$, $p = 100 \text{ cm yr}^{-1}$, an average collection efficiency $E = 10^{-2}$ and volume-mean drop radius, $R = 0.25 \text{ mm}$, then $\tau_w \approx 10$ days. To improve the accuracy of τ_w as given by (4), and similarly for snow, it is most essential to obtain more accurate estimates for the long term average collection efficiencies; they are uncertain by about an order of magnitude!

DRY REMOVAL

In contrast to wet removal, dry deposition is a surface phenomenon; nevertheless, it is important to consider dry transport through the atmosphere since in many cases this downward transport can be the rate limiting stage of the overall dry removal process. A result that illustrates this point is the detection of Sahara dust at Caribbean sampling sites; in this case, vertical transport down through a capping inversion from desert warmed air aloft inhibits the dust's deposition to the ocean. To quantify this concept it is useful to introduce the familiar resistance model which, similar to diffusion K-theory, can be described as "not useful in principle, only in practice" (credited to Corrsin by Gifford, 1968). To develop a resistance model for the atmosphere it is convenient to define first an overall, downward transfer velocity k with which the dry flux becomes $D = k(x_A - x_E^a)$. Here the subscripts A and E on the air concentration x represent some convenient layer aloft and at the earth's surface, respectively. In this form, the flux is proportional to a "driving" concentration "potential difference"; the proportionality constant k then appears like an electrical conductance. Next, if the atmosphere is considered to be divided into a series of layers A, B, C, and D (which might identify, for example, aloft, boundary, constant flux or canopy and deposition layers) and if the flux is the same through all layers, then conductances for each layer can be defined via $D = k_A(x_A - x_B) = k_B(x_B - x_C) = k_C(x_C - x_D) = k_D(x_D - x_E)$. Alternatively, $D = k_a(x_A - x_E) \equiv k_a[(x_A - x_B) + (x_B - x_C) + (x_C - x_D) + (x_D - x_E)]$ and upon substituting into this last expression $(x_A - x_B) = D/k_A$, etc., we obtain the desired result

$$k_a^{-1} \equiv r_a = r_A + r_B + r_C + r_D \equiv \Sigma(k_i)^{-1}. \quad (5)$$

In this form it is seen that the overall resistance to transfer through the atmosphere $r \equiv k_a^{-1}$ is equal to the sum of the resistances in the individual layers, $r_i = k_i^{-1}$. It is of course true that different meteorological conditions can cause substantially different resistances in different layers, e.g., for Sahara dust transport across the Atlantic. However, on a long-term-average basis, it

appears that $r_A + r_B + r_C$ typically sum to about 1 s cm^{-1} (i.e., the average transfer velocity to the layer immediately adjacent to the surface is about 1 cm s^{-1}). In contrast, though, the transfer resistance for many pollutants is substantially larger in the deposition layer or within the receiving surface, itself. Consequently it is necessary to consider these surface and near surface resistances in more detail.

For global scale pollutants, the most important surface receptors are the oceans. In general, knowledge about pollutant dry deposition to oceans and lakes is severely restricted by a lack of data (for a review, see Slinn et al, 1977). Probably most is known for gases (Liss and Slater, 1974). In this case, it is convenient to identify, separately, transfer through the atmosphere or gas phase, $D = k_g(x_b - x_i)$ and transfer in the liquid phase, $D = k_l(C_i - C_b)$. Here the subscripts g, b, i and l represent gas phase, bulk, interface and liquid phase where the bulk concentration are measured at convenient heights (depths) in the atmosphere (ocean). At the interface, at least for gases which form simple solutions, Henry's law prevails: $x_i = HC_i$. Finally, if an overall transfer velocity is defined via $D = k_0(x_b - HC_b)$ where HC_b is the air concentration which would be in equilibrium with the existing bulk concentration of the gas C_b in the liquid, then algebra as in the previous paragraph leads to

$$\frac{1}{k_0} = \frac{1}{k_g} + \frac{H}{\alpha^* k_l} \quad (6)$$

where $\alpha^* > 1$, an effective solubility coefficient, has been introduced so that this formalism can also be applied to the case of reactive gases; for example, for SO_2 , $\alpha^* \approx 10^3$ (Liss and Slater, 1974). In (6) the overall resistance k_0^{-1} is seen to be the sum of an atmospheric resistance $r_g = k_g^{-1}$ plus a resistance in the liquid phase $r_l = [H/(\alpha^* k_l)]^{-1}$. In Liss and Slater's survey, they conclude that the following values are representative, long-term-averages for the oceanic case: $k_g \approx 0.8 \text{ cm s}^{-1}$, $k_l \approx 20 \text{ cm hr}^{-1}$. Similar values can be expected for lakes. With this information and data and theory for H and α^* these authors conclude that for gases of low solubility (H near unity) and unreactive in seawater (α^* near unity) then $r_l \gg r_g$ (e.g., N_2 , O_2 , CO_2 , CH_4 , N_2O , noble gases) and therefore the overall transfer is controlled by liquid phase transfer. In contrast, for gases with high solubility ($H \ll 1$) and/or rapid aqueous phase chemistry ($\alpha^* \gg 1$) then $r_g \gg r_l$ (e.g., H_2O , SO_2 , NO_2 , NH_3 , HCl , HF). Certain pesticides and PCB's (see later) are borderline cases between these two extremes. In the case of particles, liquid phase resistance can be ignored and the net dry flux can be parameterized in terms of deposition and resuspension velocities (Slinn, 1976c): $D = v_d x_b - v_r C_b \equiv v_d(x_b - x_*)$ where x_* is the particle concentration

in air which would be in equilibrium with the existing bulk particle concentration C_b in the ocean. The particle dry deposition velocity v_d (or k_g) appears to depend primarily on transfer across the atmosphere's viscous sublayer. Available water/wind tunnel data (Müller and Shuman, 1970; Sehmel and Sutter, 1974) suggests that at low to moderate wind speeds the dominant contributors to particle dry deposition to the ocean are simply Brownian diffusion and gravitational settling: $v_d \approx v_g + 0.8 \text{ cm s}^{-1} / Sc^{2/3}$ where v_g is the gravitational settling velocity and $Sc = \nu/D$ is the Schmidt number in which ν is the kinematic viscosity of air ($\nu \approx 0.15 \text{ cm}^2 \text{ s}^{-1}$) and D is the particle diffusivity in air. If this data can be extrapolated to the oceanic case then it suggests that dry deposition of particles to the ocean is generally ignorable compared to wet deposition. However, this data and no existing theories properly account for capture of particles by spray, particle impaction on realistic waves, phoretic effects, or particle growth by water vapor condensation (Slinn et al, 1977.) Consequently it is clear that much further research is required in this subject area before accurate assessments can be made.

Similar analyses are appropriate for dry deposition of particles and gases to surfaces on land. From the recent review by Chamberlain (1975) it is seen that most resistance to the transfer of reactive gases (SO_2 , I_2 , O_3) to vegetation or moist soil occurs in the atmosphere. This leads to the familiar transfer velocity of about 1 cm s^{-1} (or u_*^2/\bar{u} or a few percent of \bar{u} where u_* is the friction velocity and \bar{u} is the mean wind speed at a convenient reference height, usually 1 m above the canopy). However, even for reactive gases, the surface resistance is expected to become increasingly important when stomata are closed, humidity is low or, for example, for dry sandy soil. Nevertheless, assuming a long-term-average transfer velocity of about 1 cm s^{-1} for transfer of reactive gases across the lower atmospheric layers to typical surfaces in the northeastern U.S. is probably one of the more accurate assumptions made. For less reactive or less soluble gases (e.g., CO_2 , NO , PAN , CO) the data obtained by Hill and Chamberlain (1976) suggests that the dry transfer is controlled within the surface receptor (Slinn, 1976b). The best available procedure for residence time estimates for such gases is probably to use the available data, even though the vegetation used in the laboratory experiments may not be representative for the area of interest. A substantial amount of information is available about dry deposition of particles to smooth surfaces (for a review, see Slinn, 1976d) but most of this information can not correctly be applied to typical environmental problems. In contrast, very little is known about particle dry deposition to rough surfaces and

vegetative canopies. Preliminary data (e.g., Sehmel and Hodgson, 1976) and theory (e.g., Slinn, 1976b) suggest, however, that the filtration effect of canopies is, in many cases, sufficiently great so that dry deposition of particles, regardless of size, can be assumed to be controlled by transfer through the upper layers of the atmosphere. If correct, this will result in the reappearance of the ubiquitous dry deposition velocity of about 1 cm s^{-1} (or u_*^2/\bar{u}). Further research is definitely required here; indeed, in view of suggestions of soon-to-be-promulgated sulfate regulations in the U.S., it can be said that research results are required urgently.

To develop estimates for dry removal's contribution to a pollutant's residence time it is necessary to obtain suitable parameterizations not only for the transfer velocities but also for the pollutant's vertical distribution in the atmosphere. This can be seen from a simple box (or control volume) model and leads to

$$\tau_d = h_d/k_0 \quad (7)$$

where k_0 is the overall transfer (or dry deposition) velocity and $h_d = \int x dz/x_b$ is a dry deposition scale height. Notice that although h_d has the same form as the similar wet scale height h_w introduced in (3), nevertheless these two heights are not expected to be the same since, for example, the integral defining h_w is to be evaluated only during periods of precipitation. As an example of the use of (7), if $h_d = 5 \text{ km}$ and $k_0 = 0.5 \text{ cm s}^{-1}$ then $\tau_d \approx 10d$. In contrast, many authors are apparently inclined to use substantially different values in (7) and to conclude that dry removal is substantially more efficient; e.g., with $h_d \approx 1 \text{ km}$ which is a typical, annual-average mixed depth for the northeastern U.S. (Holzworth, 1972) and $k_0 \approx 1 \text{ cm s}^{-1}$ then the numerical value of (7) is about 1 day. However, such estimates fail to appreciate even the common nighttime inversion which essentially shuts off transfer to the surface of pollution mixed more deeply during the previous day. It is inadequate simply to average the nighttime and daytime mixed heights and it should also be appreciated that with low nighttime inversion conditions or large scale subsidence then wind speeds are frequently lower, further reducing the dry deposition velocity. Note also that pollutants trapped above an inversion are usually transported farther by the higher wind speeds. As a first-order alternative in the case of relatively weak large scale atmospheric motions, perhaps it would be more appropriate to assume for summertime conditions that every night, dry removal completely cleans the lowest, say, 300 m and that during the day, dry removal from the, say, 2 km mixed height is negligible.

This simple model yields $\tau_d \approx 1$ wk. Certainly, however, further research is required that properly accounts for the meteorological factors influencing dry removal.

CONCLUDING EXAMPLES

To conclude this presentation it might be of interest to demonstrate estimates of residence times for a number of atmospheric trace constituents, if for no other reason than to emphasize some of the uncertainties. In the general case when wet and dry removal as well as transformations participate in a pollutant's removal, then the residence time is given by

$$\frac{1}{\tau} = \frac{1}{\tau_w} + \frac{1}{\tau_d} + \frac{1}{\tau_t} \quad (8)$$

If it is desired to envision an electrical analogue for (8) then the different removal paths appear like resistances in parallel. As briefly mentioned earlier, for some pollutants the smallest resistance is via physical/chemical transformations. For example, τ_t for SO_2 is probably about 1 day although it appears to depend strongly on humidity, insolation, and concentrations of other trace gases such as NH_3 . Photochemical transformations probably dominate the "removal" of some of the otherwise-almost-inert, low molecular weight halogenated hydrocarbons of recent environmental concern although the rate limiting stage may be their transport to the stratosphere (\sim years). However, consistent with the rest of this presentation, the emphasis here will be on removal dictated by wet and/or dry deposition.

Early estimates for the residence time of aerosol particles suggested a strong dependence on particle size but more recent results, referenced earlier, suggest that if there is any dependence at all, it would be quite modest. Thus, particles smaller than $0.05 \mu\text{m}$ radius rapidly coagulate with larger particles, including cloud particles, and with collectors at the earth's surface. Essentially all larger particles can act as cloud droplet nuclei and, even if they do not, preliminary evidence suggests that dry deposition to most environmental surfaces is much more efficient than to smooth surfaces in the laboratory. Still, however, the long-term average residence time of particles is not known at least to within a factor of 2 or 3. Notice that if $\tau_w = \tau_d = 10\text{d}$ is substituted into (8) then $\tau = 5$ days.

In contrast to the suggested, particle-size-independent residence time for aerosols, it is clear that the residence time for gases is strongly dependent on their chemical reactivity and solubility in water. Gases with large solubility coefficients (e.g., for the pesticides: DDT, $\alpha = 6.2 \times 10^2$; Aldrin, $\alpha = 1.9 \times 10^3$; Lindane, $\alpha = 5.0 \times 10^4$; Dieldrin, $\alpha = 1.3 \times 10^5$; data from Junge, 1975b) are quite

efficiently removed by rain or by dry deposition to lakes, oceans, and other surfaces with substantial water. For example, since for these gases the washout ratio $r = \alpha$, then from (3) τ_w for Dieldrin is about 10 days and estimates for the other listed pesticides can be scaled proportionately with the inverses of their solubility coefficients. From (6) it is seen that these large solubility coefficients dictate that dry transfer to lakes and oceans is rate limited by transfer through the atmosphere. However, it is suggested (Munnich, 1971; Slinn et al, 1977) that it is inappropriate to use a transfer velocity to the oceans of about 0.8 cm s^{-1} because of the reduced Brownian diffusivity of these large molecules. For example, if the appropriate reduction factor is $\text{Sc}^{2/3}$ as for particles, then for DDT $k_g \approx 0.1 \text{ cm s}^{-1}$ and then from (6) and (7), $\tau_d \approx 1$ mo. For some of the PCB's with $10^0 \leq \alpha \leq 10^2$ (Junge, 1975b) and for gases such as $^{14}\text{CO}_2$ ($\alpha=1$) then their transfer is liquid phase controlled. For $\alpha = 1$ and $k_1 = 20 \text{ cm hr}^{-1}$ then from (6) and (7), $\tau_d = 3$ yrs which although quite long, is substantially shorter than the corresponding values of τ_w . For other gases such as CO_2 ($\tau \approx 10$ yrs) and O_2 ($\tau \approx 10^3 - 10^4$ yrs) it should be mentioned that these values might more appropriately be described as atmospheric turnover times to emphasize that biological or geological processes actually control their ultimate removal from the atmosphere (Junge, 1972).

Finally, it may be of interest to address a practical problem of considerable recent interest in the U.S. The problem is to identify and possibly control sources which contribute to the potential health hazard from annual average sulfate concentrations in many parts of the northeast in excess of $10 \mu\text{g m}^{-3}$. Some suggestions derived from this review are, first, that probably most SO_2 released from tall stacks at fossil fuel plants is not dry deposited with a value near 1 cm s^{-1} and $\tau_d \approx 1$ d; instead, because of rate limiting transfer aloft especially during nights, τ_d would be several to perhaps 10 days. Meanwhile, however, most SO_2 is probably oxidized to SO_4 and these sulfate particles would be expected to have an average residence time of about 5 days. Of course, large variations about the average value are to be expected. This suggests that all upwind sources within about 1000 miles of a given site contribute to its atmospheric sulfate burden. However resuspension of previously deposited and of natural sulfate particles should not be underestimated, especially because the chemical form of the sulfate particles sampled at air monitoring stations is rarely determined and because the price tag for SO_2 controls is so high. Thus for example, it should not go unnoticed that high concentrations of sulfate particles sampled in Texas and Utah are probably resuspended, innocuous, neutral salts (Junge, 1963; Slinn, 1976e). The most important point to be derived

from this survey, however, is that our present understanding of atmospheric removal processes is still quite primitive.

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LITERATURE CITED

Chamberlain, A. C.

1975. Pollution in plant canopies. Heat and Mass Transfer in the Biosphere, Part 1. D. A. DeVries and N. A. Afgan (Eds.), Wiley, New York, 561-582.

Gifford, F. A.

1968. Atmospheric Turbulence and Diffusion. Meteorology and Atomic Energy, D. H. Slade (Ed.), USAEC TID -24190, available from NTIS, Springfield, VA.

Hill, A. C. and E. M. Chamberlain, Jr.

1976. The removal of water soluble gases from the atmosphere by vegetation. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants (1974). R. J. Engelmann and G. A. Sehmel (Coords.), available as CONF - 740921, ERDA Symposium Series, NTIS, Springfield, VA.

Holzworth, G. C.

1972. Mixing Heights, Wind Speeds, and Potential For Urban Air Pollution throughout the Contiguous United States. AP - 101, U.S. Environmental Protection Agency. Available from NTIS, Springfield, VA.

Junge, C. E.

1963. Atmospheric Chemistry and Radioactivity, Academic Press, New York.

1972. The cycle of atmospheric trace gases - natural and man made. J. Royal Met. Soc. 98: 711 - 729.

1974. Residence time and variability of tropospheric trace gases. Tellus 26: 477 - 488.

1975 a. Processes responsible for the trace content in precipitation. Proc. Snow and Ice Symposium, Grenoble, UGGI Assembly, August, 1975, in press.

1975 b. Basic considerations about trace constituents in the atmosphere as related

to the fate of global pollutants. Proc. ACS - Symposium on Fate of Pollutants in the Air and Water Environment. Envir. Sc. and Technology, Wiley, in press.

Liss, P. S. and P. G. Slater

1974. Flux of gases across the air-sea interface. Nature 247: 181 - 184.

Möller, U. and G. Shumann

1970. Mechanisms of transport from the atmosphere to the earth's surface. J. Geophys. Res. 75: 3013 - 3019.

Munnich, K. O.

1971. Atmosphere - ocean relationships in global environmental pollution. Special Envr. Rept. No. 2, Meteorology as Related to the Human Environment, WMO-No. 312, Geneva.

Sehmel, G. A. and W. H. Hodgson

1976. Particle dry deposition velocities. Ibid, Hill and Chamberlain (1976).

Sehmel, G. A. and S. L. Sutter

1974. Particle dry deposition rates on a water surface as a function of particle diameter and air velocity. J. de Rech. Atmos. III, 911 - 918.

Slinn, W. G. N.

1976a. Precipitation scavenging: some problems, approximate solutions, and suggestions for future research. Precipitation Scavenging (1974). R. W. Beadle and R. G. Semonin (Coords.). Available as CONF - 741014, ERDA Symposium Series, from NTIS, Springfield, VA.

1976b. Some approximations for the wet and dry removal of particles and gases from the atmosphere. J. Air, Water and Soil Pollution, in press.

1976c. Formulation and a solution of the diffusion, deposition, resuspension problem. Atmos. Env., in press.

1976d. Dry deposition and resuspension of aerosol particles -- a new look at some old problems. Ibid. Hill and Chamberlain (1976).

1976e. Why not "cloud scrubbers". Bul. Am. Met. Soc., in press.

Slinn, W. G. N., L. Hasse, B. B. Hicks, A. W. Hogan, D. Lal, P. S. Liss, K. O. Munnich, G. A. Sehmel and O. Vittori, 1977. Wet and Dry Removal Processes. Tropospheric Transport of Pollutants to the Ocean, J. M. Prospero (Ed.), U. S. Nat. Ac. Sciences, Washington, D. C., in press.

Dry Removal of Air Pollutants by Vegetation Canopies¹

J. G. Droppo²/

This study describes studies being conducted to quantify dry removal rates of air pollutants by natural surfaces. Processes involved are discussed in a resistance model framework. Values from the literature and results of current field tests relating to rates of dry removal are summarized for selected gases and particles, and the experimental accuracy of particulate sulfur deposition values is discussed.

INTRODUCTION

Concern about the fate and effects of atmospheric pollutants has intensified interest in natural removal processes. One of these processes is dry deposition of gases and particles on vegetative canopies, the subject of studies currently underway at Battelle's Pacific Northwest Laboratories. Rates of removal by vegetative canopies and other surfaces are being measured in field studies to determine pollutant budgets on large scales and to assess local impacts from single sources. These data will be used as input to mathematical prediction models of dry deposition processes.

Dry deposition is the direct transfer of a material from the atmosphere to vegetation or any other material which comprises the earth's surface by processes other than those involving liquid water droplets. Dry deposition reduces ambient air pollutant concentrations and determines the potential for an increase in the pollutant concentration on or within the receptor material. Processes affecting dry deposition of a specific pollutant include gravitational settling, transport by atmospheric turbulence, impaction, concurrent surface fluxes, and chemical reactions. Quantification of these processes is necessary to evaluate potential pollutant impacts, both in the air and on the

receptors. Battelle is developing a comprehensive model which evaluates dry deposition of pollutants on various surfaces under varying conditions. This paper describes the model, reviews dry deposition data for a number of pollutants on various canopies and surfaces, and gives results of current studies.

MODELING OF DRY DEPOSITION PROCESSES

Past efforts to model dry deposition of smaller particles and gases have been limited by a lack of data defining the relative importance of the various operative processes. The following model description, which is based on synthesis of a number of references (Bennett et al., 1973; Droppo, 1974; Garland, 1974b; Hicks, 1974; Wagonner and Reifsnyder, 1968; Hill, 1971; Rasmussen et al., 1974; Select Research Group in Air Pollution Meteorology, 1974; Slinn, 1974), provides a conceptual framework for organizing these processes for subsequent study. This model is similar to the resistance models proposed for water vapor fluxes from canopies. Dry deposition may be considered as a concurrent flux to the surfaces and in certain cases to plant stomata.

The dry deposition of a substance may be a function of many processes, or one process may dominate all the others. A typical list of interrelated factors would include:

Atmospheric factors:	Wind speed, turbulence, temperature structure, moisture, concentrations of pollutant being studied
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and other pollutants,
solar radiation and long
wave radiation.

Receptor factors:	Surface roughness, moisture, physical and chemical nature, physiological state, mem- branes, internal and surface pollutant concentrations, and status of stomata.
Pollutant factors:	Chemical and physical prop- erties, solubility densities, size, shape, settling velocity.

Dry deposition involves flux by many different transport mechanisms. These include gravitational settling, atmospheric eddy transport, and molecular transport in the air near the surfaces and from the surfaces into the receptor. These mechanisms may be grouped into regimes: 1) the atmospheric regime, 2) the surface air layer regime, and 3) the surface-into-the-receptor regime. Various processes dominate the transport in each regime.

The atmospheric regime refers to the air layer over the surfaces. In this regime pollutant transport is primarily by eddy motions of air. The surface air layer regime refers to the thin layer immediately over the receptor, where molecular transport is important. The surface-into-the-receptor regime refers to the rate at which pollutants are transported into the receptor. In this regime molecular transport, physiological and chemical processes may variously dominate the flux.

The chemical change of one pollutant species to another is a sink that may be a parallel process in any of the regimes. When considering the constant flux layer chemical reactions within the atmospheric regime are not normally rapid enough to be significant. Reactions at the surface (such as destruction of ozone) and within the surface (such as physiological uptake of SO₂) (deCormis, 1968) can be limiting in some situations. The model does not consider the potential for saturation of various sinks. For example, a plant's resistance to a pollutant may be a function of the concentrations already within the plant. Consideration of such factors by the model would mean that time must be included as a variable in the analysis.

Each regime is assigned a resistance (r) which defines the extent to which that regime limits the deposition rate. For a given situation:

$$\frac{1}{r_T} = \frac{1}{r_a + r_\ell + r_i} + \frac{1}{r_g} \quad (1)$$

where the subscripts T, a, ℓ , i and g refer to total, atmospheric, surface air layer, internal (surface into receptor), and gravitational resistances. Once total resistance is defined, boundary condition inputs into diffusion models are possible.

Resistance Terms in the Model

Each of the resistance terms on the right of Equation 1 can be considered as a separate input for the dry deposition process in this formulation of the model. These terms are discussed below.

Atmospheric Resistance

The transport processes for a given pollutant in the atmospheric regime can be described in terms of the transfer processes for other materials or properties. For example, the atmospheric resistance for the material might be assumed to be equal to that of momentum (τ),

$$r_a = r_\tau = \frac{u(z)}{u_*^2} \dots \quad (2)$$

where $u(z)$ is the wind speed at height z and u_* is the friction velocity. This is the reciprocal of a relationship developed by Chamberlain and Chadwick (1953) for a "deposition velocity".

Surface Resistance

The dependence of deposition on near-surface mechanisms comprises the surface resistance term r_ℓ . Owen and Thompson (1963) defined this resistance, which arises from molecular interaction in the layer just over the surface, in terms of a nondimensional Stanton number (B^{-1}).

Equation 2 assumes that the total resistance for momentum is atmospheric. The mechanisms of transport at the surface for momentum and mass differ. Momentum is transferred by pressure forces on the receptor, while mass must be carried to the surface by gravity, impaction or molecular transport mechanisms. The latter processes result in the surface resistance.

Internal Resistance

For plant tissue, resistance is a more complicated function of the plant properties and processes. Factors such as membrane pressures and pollutant concentrations may limit transport. The opening and closing of stomata

is important for gases. Control of stomata openings for certain plants has been shown to depend in a complicated fashion on the ambient air concentrations of CO₂, H₂O and SO₂. Hence, resistance in plants appears to be the most difficult persistence to assess, since the actual properties of the surface and receptor must be defined.

Rates of Reaction Resistances

The limiting processes may be different for gases, such as ozone, which are highly reactive. Destruction of ozone occurs at the surfaces and perhaps also in areas shaded from sunlight by the surfaces. The gravitational resistance term (r_g) gives a lower limit for the rate of any deposition. The resistance is the inverse of the appropriate settling velocity V_g ,

$$r_g = \frac{1}{V_s} \quad (3)$$

Effective Surface Resistance

An effective surface resistance, r_s , is used to include processes other than atmospheric and gravitational. That is,

$$\frac{1}{r_T} = \frac{1}{r_a + r_s} + \frac{1}{r_g} \dots \quad (4)$$

In practice the effective surface resistance is the additional resistance a pollutant encounters over the atmospheric eddy delivery resistance. The potential rate of transport in the atmospheric eddy transport regime is assumed to be the same for all gases and small particles, a function of atmospheric turbulence alone.

Deposition Velocity

The simplest relationship for dry deposition of either gases or particles is based on an assumption relating the ambient air concentration (χ) and the rate of deposition (G). The rate of deposition is assumed to be directly proportional to the ambient air concentration at a defined height over the surface (z). The constant of proportionality incorporates the units of length per time and is referred to as a "deposition velocity" (V_d) (Chamberlain and Chadwick, 1953). The equation is:

$$G = v_d / \chi_z \quad (5)$$

with the height traditionally assumed to be 1 meter. The deposition velocity has been a framework for much of the research in dry

deposition and will be used for summarizing these previous efforts. The deposition velocity through all regimes is the inverse of the total resistance:

$$V_d = \frac{1}{r_T} \quad (6)$$

Gases

Table 1 is a summary of dry deposition velocity data for various gases on different surfaces. Iodine, SO₂, O₃, NO₂ and HF all have reasonably high deposition velocity values. The limited data on NO indicate a much lower value. The high and low relative deposition rates of NO₂ and NO are supported by the intermediate value for NO_x.

The effect of vegetative canopies on deposition is not clearly defined. For example, increases in surface roughness and area are expected to lead to high deposition rates. Although this is generally true for SO₂, the rougher surface (pine forest) has a lower deposition velocity than other canopies and surfaces. Other factors discussed earlier may be limiting the deposition.

The effect of atmospheric delivery is obvious in the data that include groupings by atmospheric stability. These studies of the deposition of SO₂ and other gases demonstrate that various regimes may be limiting under differing conditions and that a range of deposition velocities can result.

Several studies have considered the penetration of materials into canopies by dry deposition. Markee (1971) considered the dry deposition of iodine as a function of leaf surface area for low canopies. He found that deposition increased with increasing leaf area. The absorption of gaseous air pollutants by alfalfa canopies and resultant profiles were studied in an environmental growth chamber (Hill, 1971). Hydrogen fluoride, SO₂ and NO₂ profiles suggested efficient removal by both the upper and intermediate surface vegetation. Table 2, which is derived from Hill's data, shows this efficiency of transfer of momentum and gases as a function of height. These data have been normalized to the top height to allow comparison of profile shapes. Assuming the transport mechanisms are the same for all properties in the air, the profiles may be interpreted as reflecting fluxes. These profiles indicate that momentum deposition is more efficient than deposition of the pollutants. Use of momentum deposition velocities will cause overestimation of the flux and the location of the deposition. Although there is significant deposition of the gases (except

Table 1. Summary of Deposition Velocities for Various Gases

Substance	Deposition Velocity (cm/sec)	Type of Surface/ Number of Experiments ()	Methodology and Reference
Iodine (a)	Range: 1.1 - 3.7 Mean: 2.1	Grass (7)	Field experiments (Chamberlain, 1953 and 1966)
Iodine	Range: 0.3 - 1.3 Mean: 0.75	Clover leaves (4)	
Iodine	Range: 0.6 - 2.0 Mean: 1.3	Paper leaves (4)	
Iodine	Range: 0.3 - 0.9 Mean: 0.62	Filter paper (5)	
Iodine	Range: 0.09 - 2.43 Mean: 0.87	Grass (19)	Field experiments (Bunch, 1966 and 1968)
Iodine	Range: 0.6 - 0.7 Mean: 6.5	Carbon (12)	(Hawley et al., 1966; Markee, 1971; Zimbrick et al., 1969)
SO ₂	2.8	Alfalfa canopy in chambers	Windspeed: 1.8 to 2.2 m/s (Hill, 1971)
SO ₂	Range: 1.0 - 2.06 Mean: 1.3	Grass (14)	Surface flux determination for SO ₂ (Garland et al., 1974a)
35 SO ₂	Range: 0.5 - 2.6 Mean: 1.3	Grass (3)	Radioactivity labeled SO ₂ release used as tracer in field experiments (Owers and Powell, 1974)(b)
35 SO ₂	0.5	Water (1)	Radioactivity labeled SO ₂ release used as tracer in field experiments (Owers and Powell, 1974)
SO ₂	Range: 0.27 - 1.5 Mean: 0.76	Grass (5)	(Shepherd, 1974)
SO ₂	1.3	Grass (1)	Surface flux determination for SO ₂ (Droppo et al., 1976)
SO ₂	1.8	Short grass	Surface flux (radioactive tracer) (Garland, 1974b)(b)
SO ₂	(0.84) 1.3	Medium grass	
SO ₂	0.91	Bare calcareous soil	
SO ₂	2.2	Fresh water (pH = 8)	
SO ₂	<0.50	Forest pine	
SO ₂	2.4 2.6 0.5	Lapse Neutral Stable	Over grass (Whelpdale and Shaw, 1974)
	1.6 0.52 0.05	Lapse Neutral Stable	Snow
	4.0 2.2 0.16	Lapse Neutral Stable	Water
NO	0	All surfaces	Not a field result (Robinson and Robbins, 1968, 1970)
NO	0.1	Alfalfa canopy	In special chambers (Hill, 1971)
NO _x	0.5	Alfalfa and oats	Derived from data in Tingey (1968) and Rasmussen et al. (1974)
NO ₂	2.0	Alfalfa canopy	Special chamber (Hill, 1971)

Table 1. Summary of Deposition Velocities for Various Gases (cont.)

HF	1.6	Alfalfa	Fumigation with constant concentrations (Israel, 1974)
	3.1	Field crops	Fumigation with constant concentrations
O ₃	Range: 0.7 - 1.7 Mean: 1.13	Several	Review of research by several authors (Galbally, 1971; Galbally, 1968a,b; Aldaz, 1969; Regener, 1969; Kelly, 1968)
O ₃	0.6 - 1.8	Soil, peat, grass	Wind tunnel experiments (Garland, 1974)
O ₃	1.4 - 6.3	Several	Decay rate experiment in box (Garland, 1974)
O ₃	1.7	Alfalfa canopy	Special chambers (Hill, 1971)

(a) There is some question about how long iodine remains a gas before attaching to particles.
(b) Estimates of surface resistance are also given in this paper.

NO), the deposition clearly occurs deeper into the canopy than does the momentum transfer, as indicated by the changes in concentration with height. Table 2, which gives the percentage changes in layers, shows that the SO₂ change is still relatively large in the lowest layer when compared with changes in the other gases.

Particles

Dry deposition of particles depends on the delivery rate in the atmosphere and on surface interactions. (Larger particles that deposit by gravitational forces are excluded from this consideration.) Transport in the atmosphere is a function of the atmospheric turbulence. At the surfaces the principle processes are impaction and molecular diffusion. Electrical

forces may also be important, depending on the mobility and charges of the particles and the electrical field. In addition, concurrent mass and heat fluxes may influence the dry deposition rate when molecular processes are important.

The wide range of field data values for dry deposition of various particles is summarized in Table 3. Included are results from the literature as well as results of current experiments at Battelle. The wide range in the values may have two origins. First, large variations are expected from situation to situation as the processes discussed above become variously limiting. Secondly, variations can be partially the result of experimental uncertainties, which are generally relatively large in dry removal rate experiments.

Table 2. Normalized Wind and Pollutant Profiles (Based on Data in Hill, 1971)

Height (cm)	% Momentum from 60 cm to Height	% SO ₂	% O ₂	% HK	% NO ₂	% NO
60	100	100	100	100	100	100
50	91	92	94	94	96	98
40 (Canopy)	37	69	74	75	90	100
30	13	47	54	59	75	93
20	8	37	42	53	62	92
10	5	22	36	51	57	94
Changes						
60-50	9	8	6	6	4	2
50-40	54	23	20	19	6	-2
40-30	24	22	20	16	15	7
30-20	5	10	12	6	13	1
20-10	3	15	6	2	5	-2

Table 3. Summary of Deposition Velocities for Various Particles

Substance	Deposition Velocity (cm/sec)	Type of Surface/ Number of Experiments	Methodology and Reference
Fission Products	0.07	Gummed Paper	Surface activity measurements particles are formed by an electric core (Megaw and Chadwick, 1956)
^{137}Cs	0.9 0.04 0.2 0.2	Water (5) Soil (15) Grass (21) Sticky paper (117)	Field release test measurements (Slade, 1968)
^{103}Ru	2.3 0.4 0.6 0.4	Water (9) Soil (16) Grass (20) Sticky paper (8)	
^{93}Zr , ^{95}Nb	5.7 2.9 1.4	Water (6) Soil (6) Sticky paper (10)	
^{141}Ca	0.7	Sticky paper	
^{127}Te , ^{129}Te	0.7	Sticky paper (8)	
Pb	0.13	Dilute HCl solution	Plastic pluviometer (Servant, 1974)
Industrial-derived Trace Elements	0.4 to 0.3	Deposition plates	Field data (Cawse and Peirson, 1972)
Soil-derived Trace Elements	0.3 to 1.0	Deposition plates	
Zinc Sulfide (2.5 μm diameter)	0.5	Sagebrush	Stable atmospheric conditions (Simpson, 1961)
Particles of 0.1 μm	0.2 to 9.2	Desert	Islitzer and Dumbauld (1963)
Natural Particulate Material	0.8 to 7.6 (7)	Great Lakes (water)	Whelpdale (1974)
Fallout	0.2 to 3.4	Fallout collectors	Monthly values (Small, 1960)
Fallout	0.51 and .75	Fallout collectors	Annual values
Total Sulfur Aerosol	0.1 to 0.3	Sagebrush (3)	Surface flux technique (Droppo, 1976)

In current dry deposition efforts, there is an attempt to separate these two factors by making an experimental accuracy estimate for each data value obtained. This appears to be a desirable procedure, since initial estimates show that the experimental accuracy of values varies widely from case to case.

Experimental Accuracy for Dry Deposition of Sulfur-Containing Particles

Although our current studies consider removal rates for a number of gaseous and particulate pollutants, the discussion here will be limited to the determination of the dry deposition rates of sulfur-containing particles. Detailed descriptions of our experimental model, equations, assumptions, data acquisition systems, field sites, and results have been

documented elsewhere (Droppo and Hales, 1974; Hadlock et al., 1976; Droppo et al., 1976).

With a combined eddy flux-gradient methodology, the accuracy of the deposition velocity computation depends on the accuracy and applicabilities of the eddy diffusivities and the accuracy of the pollutant profiles. Battelle studies indicate that either or both of these experimental accuracies may limit the accuracy of the results (Droppo et al., 1976).

Since the direct determination of pollutant eddy diffusivities is normally not possible, a suitable analogy is assumed in the transport of other quantities for which eddy diffusivity is attainable. The eddy diffusivities that have been studied are known not to be generally identical, although relationships have been derived. The applicability of a given eddy

diffusivity to a pollutant is an open question. The momentum eddy diffusivity was adopted in the current study, although the choice is somewhat arbitrary. Further research is needed to resolve this question.

Figure 1 is a plot of four computed dry deposition velocities for ambient sulfur particles over a sagebrush cover. These are not selected results, but rather four proof tests that were performed to determine how accurately deposition rates could be determined with current surface flux-gradient methodology. The first three cases (but not the fourth) met the criteria for application of the methodology. Conditions of the fourth case varied significantly from steady state, so this case is included for comparison only.

The key to the accuracy of the current methodology for particles was the attainment of sufficient accuracy in the pollutant profiles. The $\pm 1\%$ pollutant profile accuracy assumed in these plots is supported both by relative

accuracy estimates in the specially developed X-ray fluorescence analysis (Droppo et al., 1976) and in the "goodness of fit" of the concentration values to a log profile. There are too few data points to make a definitive accuracy estimate. Additional efforts are underway to better define the accuracy of removal rate determinations. Table 4 summarizes these preliminary results in terms of the resistance values defined earlier. R_T is the inverse of the deposition velocity, R_a is the atmospheric resistance (computed as equal to the momentum resistance), and R_s is the effective surface resistance computed as the difference between the total and surface resistances. The last column is the mean wind speed at 17 meters.

As far as we are aware, these preliminary data provide the first values that directly assess sulfur containing particle removal rates in the field within reasonable accuracy. The range and values are encouraging and are positive results in the first stages of this developing methodology.

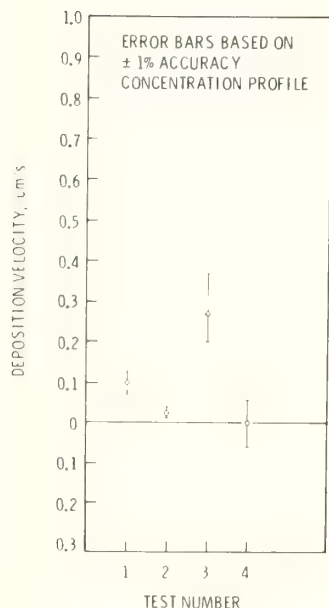


Figure 1. Deposition Velocities for Total Sulfur Particles.

Table 4. Summary of Results for Dry Deposition of Sulfur Aerosols

Test	V_d (cm/s)	R_T (s/cm)	R_a (s/cm)	R_s (s/cm)	$\bar{u}(17m)$ (m/s)
1	0.10	10.0	2.3	7.7	1.13
2	0.03	33.3	2.3	31.0	3.50
3	0.27	3.7	0.44	3.3	1.28

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LITERATURE CITED

- Aldaz, L.
1969. Flux measurements of atmospheric ozone near land and water. *J. Geophysical Research* 74:6939-6946.
- Bennett, J. H., A. C. Hill and D. M. Gates.
1973. A model for gaseous pollutant sorption by leaves. *J. Air Pollution Control Assoc.* 23(11):957-962.
- Bunch, D. F.
1966. Controlled environmental radioiodine tests (CERT). Progress Report No. 2, IDO-12053, AEC Operations Office, Idaho Falls, ID.
- Bunch, D. F.
1968. Controlled environmental radioiodine tests (CERT). Progress Report No. 3, IDO-12063, AEC Operations Office, Idaho Falls, ID.
- Cawse, P. A., and D. H. Peirson.
1972. An analytical study of trace elements in the atmospheric environment. AERE-R-7.34, available from NTIS, Springfield, VA.
- Chamberlain, A. C.
1960. Aspects of the deposition of radioactive and other gases and particles. In: *Aerodynamic Capture of Particles*, Pergamon Press, New York.
- Chamberlain, A. C.
1966. Transport of gases to and from grass-like surfaces. *Proc. Royal Society (A)*, London, 290:236-265.
- Chamberlain, A. C. and R. C. Chadwick.
1953. Deposition of airborne radioiodine vapor. *Nucleonics* 11(8):22-25.
- Chamberlain, A. C. and R. C. Chadwick.
1966. Transport of iodine from atmosphere to ground. *Tellus* 18:226-237.
- deCormis, L.
1968. Some aspects of sulfur absorption by plants subjected to an atmosphere containing SO₂. *Proc. First European Congress on Air Pollution, the Netherlands*.
- Droppo, J. G., D. W. Glover, O. B. Abby, C. W. Spicer and J. Cooper.
1976. Measurement of dry deposition of fossil fuel pollutants. Draft final report under EPA Contract 68-02-1747, Battelle, Pacific Northwest Laboratories, Richland, WA.
- Droppo, J. G.
1974. Dry deposition processes on vegetation canopies. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, CONF-740 921, ERDA Symposium Series 38*.
- Droppo, J. G. and J. M. Hales.
1974. Profile methods of dry deposition measurement. *Proc. Atmospheric-Surface Exchange of Particulate and Gaseous Pollutants, CONF-740 921, ERDA Symposium Series 38*.
- Galbally, I.
1968a. Ozone variation and destruction in the atmospheric surface layer. *Nature* 218:456-457.
- Galbally, I.
1968b. Evaluation of the Ehmert technique for measuring ozone profiles in the atmospheric surface layer. *J. Geophysical Research* 74:6869-6872.
- Galbally, I.
1971. Ozone profiles and ozone fluxes in the atmospheric surface layer. *Quarterly J. Royal Meteorological Society* 97:18-29.
- Garland, J. A., D. H. F. Atkins, C. J. Readings, and S. J. Cauhey.
1974. Technical note: deposition of gaseous sulphur dioxide to the ground. *Atmos. Environ.* 8:75-79.
- Garland, J. A.
1974. Dry deposition of SO₂ and other gases. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, CONF-740 921, ERDA Symposium Series 38*.
- Hadlock, R. K., J. G. Droppo and R. K. Woodruff.
1974. Dry deposition of sulfur dioxide and sulfur particles from Northwest fossil fuel plants. In: *BNWL-1850, Pt. 3, Pacific Northwest Laboratory Annual Report for 1973 to AEC*, available from NTIS, Springfield, VA.
- Hawley, C. A.
1966. Controlled environmental radioiodine tests (CERT) at NRTS. 1965 Progress Report IDO-12047, AEC Operations Office, Idaho Falls, ID.
- Hicks, B. B.
1974. Some micrometeorological aspects of pollutant deposition rates near the surface. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, CONF-740 921, ERDA Symposium Series 38*.
- Hill, A. C.
1971. Vegetation: a sink for atmospheric pollutants. *J. Air Pollution Control Assoc.* 21(6):341-346.
- Islitzer, N. F. and R. K. Dumbauld.
1963. Atmospheric diffusion-deposition studies over flat terrain. *International J. of Air and Water Pollution* 7(11-12):999-1022.

- Israel, G. W.
1974. Deposition velocity of gaseous fluorides on alfalfa. *Atmos. Environ.* 8:1329-1330.
- Kelly, J. J., Jr., and J. D. McTaggart Cowan.
1968. Vertical gradient of net oxidant near the ground surface at Barrow, Alaska. *J. of Geophysical Research* 73:3328-3330.
- Markee, E. H., Jr.
1971. Studies of the transfer of radioiodine gas to and from natural surfaces. ERL-ARL-29, Environmental Research Laboratories, Air Resources Laboratories, Silver Spring, MD.
- Megaw, W. J. and R. C. Chadwick.
1956. Some field experiments on the release and deposition of fission products and thorium. AERE-HP-M-114, available from NTIS, Springfield, VA.
- Owen, P. R. and W. R. Thompson.
1963. Heat transfer areas on rough surfaces. *J. Fluid Mechanics* 15:321.
- Owers, M. J. and A. W. Powell.
1974. Deposition velocity of sulfur dioxide on land and water surfaces using a ^{35}S tracer method. *Atmos. Environ.* 8:63-67.
- Rasmussen, K. H., M. Taheri and R. L. Kabel.
1974. Sources and natural removal processes for some atmospheric pollutants. Report EPA-650/4-74-032, Center for Air Environmental Studies, Pennsylvania State University.
- Regener, V. H. and L. Aldaz.
1969. Turbulent transport near the ground as determined from measurements of the ozone flux and the ozone gradient. *J. of Geophysical Research* 74:6935-6942.
- Robinson, E. and R. C. Robbins.
1968. Sources, abundance and fate of gaseous atmospheric pollutants. Final Report, SRI Project PR-6755.
- Robinson, E. and R. C. Robbins.
1970. Gaseous nitrogen compound pollutants from urban and natural sources. *J. Air Pollution Control Assoc.* 20:303-306.
- Select Research Group in Air Pollution Meteorology.
1974. Second Annual Progress Report, Volume II. Report EPA-650/4-74-045-6, Pennsylvania State University.
- Servant, J.
1974. Deposition of atmospheric lead particles to natural surfaces in field experiments. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants*, CONF-740 921, ERDA Symposium Series 38.
- Shepard, J. G.
1974. Measurements of the direct deposition of sulphur dioxide into grass and water by the profile method. *Atmos. Environ.* 8:69-74.
- Simpson, C. L.
1961. Some measurements of the deposition of matter and its relation to diffusion from a continuous point source in a stable atmosphere. HW-69292, available from NTIS, Springfield, VA.
- Slade, D. H.
1968. Meteorology and atomic energy 1968. TID-24190, available from NTIS, Springfield, VA.
- Slinn, W. G. N.
1974. Atmospheric aerosols: sources, concentrations and budgets. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants*, CONF-740 921, ERDA Symposium Series 38.
- Small, S. H.
1960. Wet and dry deposition of fallout materials at Kjeller. *Tellus* 12:308-314.
- Tingey, D. T.
1968. Foliar absorption of nitrogen dioxide. M.A. Thesis, Dept. of Botany, University of Utah.
- Waggoner, P. E. and W. E. Reifsnyder.
1968. Simulation of temperature, humidity and evaporation profiles in a leaf canopy. *J. Applied Meteorology* 7(3):400-409.
- Whelpdale, D. M.
1974. Dry deposition over the Great Lakes. *Proc. Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants*, CONF-740 921, ERDA Symposium Series 38.
- Whelpdale, D. M. and R. W. Shaw.
1974. Sulphur dioxide removal by turbulent transfer over grass, snow and water surfaces. *Tellus* 26:196-205.
- Zimbrick, J. D. and P. G. Voilleque.
1969. Controlled environmental radioiodine tests (CERT) at NRTS. Progress Report No. 4. IDO-12065, AEC Operations Office, Idaho Falls, ID.

Modeling the Uptake of SO₂ by Vegetation¹

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Abstract.--Transport of SO₂ is traced from its sources through the atmosphere to the effective sink within the plant. The model is based on the resistance analog to Fick's diffusion equation. At low ambient concentrations environmental parameters are shown to affect SO₂ removal. The model generates information on the uptake of a single leaf. Vegetative parameters include leaf and stomatal factors and LAI (leaf area index). Generalized values of LAI are used to estimate SO₂ uptake on a regional basis. The model is applied to calculate the SO₂ uptake in energy and mineral resource regions of the Western United States where ambient levels of SO₂ will increase as a result of proposed development.

INTRODUCTION

The Northern Great Plains, including Montana, Wyoming, North and South Dakota and Nebraska, contain estimated reserves of 3.3 trillion tons of coal. Much of this coal is low in sulfur and sufficiently near the surface for economical strip mining. The Northern Great Plains Resources Program (NGPRP) (EPA 1974) identified high, medium, and low scenarios for the development of mine-mouth power plants and coal gasification facilities by 1985 and by 2000. In spite of the fact that these facilities will each meet ambient air quality standards as well as the New Source performance standards for sulfur dioxide (SO₂), on a regional basis one must expect some increase in ambient concentration of SO₂.

This increase in pollution comes in air which has been estimated (Fox 1976) to be among the cleanest in the United States. The climate of this region is influenced by a gradation of precipitation from a low of 10 inches annually in eastern Montana and Wyoming to over

22 inches in North Dakota. The native vegetation is a grassland ecosystem, which basically grades with the precipitation pattern from short grass to tall grass prairie. A question of paramount concern is, what impact will the increase in ambient sulfur dioxide have on the natural ecosystem?

This paper represents a multistep procedure to assess the effect of low ambient concentrations on grassland systems. Since consideration of the soil uptake is much beyond the scope of our paper, as is sulfur metabolism in natural grasses, the contribution is limited. Specifically, we develop a numerical model capable of simulating the uptake of sulfur dioxide, and use the model to estimate SO₂ removal by vegetation on a regional basis. As an example, we estimate the incremental uptake in the Northern Great Plains based upon estimates of the ambient concentration associated with the 1985 and 2000 development scenarios.

MODEL

For the purpose of this model an estimated annual average ambient concentration of sulfur dioxide is applied uniformly to the vegetation. At the leaf--atmosphere interface, the flux of gas into the system is governed by a series of resistances. The resistance analog to Fickian diffusion is used to simulate transport through the leaf to an effective sink in the mesophyll. The removal capacity of this sink is a function

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of sulfur dioxide solubility in the water layer surrounding the cells of the mesophyll.

Through the use of the resistance analog, flux through the plant system is estimated by:

$$F_{SO_2} = \frac{C_a - C_i}{R_T} \quad (1)$$

Where F_{SO_2} = Flux of SO_2 into the plant ($\mu g/m^2\text{-sec}$)
 C_a = ambient volumetric concentration ($\mu g/m^3$)
 C_i = internal volumetric concentration
 R_T = total resistance (sec/m)
 $= R_b + R_s + R_{ss}$

The resistance is the sum of the boundary, stomatal, and substomatal resistances, since it is assumed that these act sequentially. The boundary resistance (R_b) is given by

$$R_b = \frac{0.4}{D} \sqrt{\frac{L}{\bar{u}}}$$

where

0.4 = empirical coefficient ($cm/sec^{1/2}$)
 L = leaf length in crosswind direction (cm)
 \bar{u} = mean wind speed (cm/sec)
 D = molecular diffusion coefficient for SO_2 in air (cm^2/sec)
 $= 0.115 cm^2/sec$ (Chamberlain 1966)

The stomatal resistance (R_s) is given by (Nobel 1974)

$$R_s = (d_s + r_s)/Dna$$

where

d_s = effective stomatal depth (cm)
 r_s = stomatal radius (cm)
 n = number of stomates per leaf
 $a = \frac{\text{area of stomates}}{\text{area of leaf}}$

Radiation is considered to have a second-order effect on stomatal resistance, since the grasses under concern here reach maximum stomatal opening about one hour after sunrise (Meidner and Mansfield 1968):

$$R_{ss} = x/D$$

where

x = mean path length to the cells of the mesophyll from the stomatal pores (cm)

The concentration, C_i , of SO_2 within the plant is an undeterminable quantity. However, since SO_2 is highly soluble in water and since mesophyll tissue is largely water, it is likely that the internal concentration drives SO_2 into solution in the mesophyll water. This approach is similar to that adopted by Murphy et al. (1976) and others. Solubility of SO_2 in water is governed by Henry's Law:

$$C_i = \chi H \quad (2)$$

where

χ = concentration of SO_2 per unit water volume
 H = Henry's Law constant

H is not strictly a constant, but has a rather pronounced variation with temperature. Johnstone and Leppa (1934) published solubility data for low concentrations of SO_2 in water. At temperatures of 0, 10, 18, 25, 35, and 50°C. For use in the model, values of H were required for all temperatures within a range from about 5°C to 40°C. A regression analysis yielded the following equation for H , the Henry's Law constant:

$$H = 0.013697 + 0.000495(T) + 0.000011(T^2)$$

where T is °C. This equation has an excellent least squares fit ($R = .978$) and it was used rather than linear extrapolation. It is possible to estimate the incremental increase of concentration due to the calculated flux of SO_2 by plants. This is simply

$$\Delta \chi = F_{SO_2} \frac{A}{V} \Delta t \quad (3)$$

where

$\Delta \chi$ = increase in concentration of SO_2 in mesophyll water
 A = surface area of mesophyll per stoma
 V = volume of water in the mesophyll surrounding a typical stoma
 Δt = interval of time flux is operating.

The concentration becomes

$$\chi = \chi_0 + \sum_i (\Delta \chi)_i \quad (4)$$

where χ_0 is the initial concentration.

Combining (1)-(4) yields an expression for the flux of SO_2 into a plant as a function of the previous time history so that

$$(F_{SO_2})_{i+1} = \frac{C_a - H(\chi_0 + \sum_i (F_{SO_2} \Delta t)_i \frac{A}{V})}{R_T} \quad (5)$$

where $(F_{SO_2})_{i+1}$ = flux of SO_2 to the plant at time $t = \Delta t + \sum_i \Delta t$

From equation (5) there are two obvious environmental parameters affecting the flux of SO_2 to the plant, wind velocity and air temperature. Velocity affects R_T since boundary layer resistance, R_b , is inversely proportional to the one-half power of velocity. Thus the flux goes as

$$F_{SO_2} \propto \frac{K_1}{K_2 + \frac{1}{u^{1/2}}}$$

for any particular species; that is, it increases as velocity increases. A similar dependence has recently been shown by Murphy (1976). Temperature affects the Henry's Law constant linearly to first order above $5^\circ C$. Increasing temperature thus reduces the flux of SO_2 to the plant.

Using equation (5) it is possible to sum over a period of time the total accumulation of SO_2 , U_{SO_2} , by a vegetated surface as

$$U_{SO_2} = \sum_i (F_{SO_2} \Delta t)_i A \text{ na LAI} \quad (6)$$

where

U_{SO_2} = total uptake (μg)

LAI = leaf area index = $\frac{\text{area of leaves}}{\text{surface area}}$

Such uptake will continue so long as there is a sink for SO_2 in the mesophyll, namely until $X \geq X_{sat.}$, where $X_{sat.}$ is the equilibrium saturation of SO_2 in water. In practice, the calculation is performed for 1 sec. time intervals, $\Delta t = 1$ sec. until $X \geq X_{sat.}$ at which time the flux is assumed to stop.

The above calculations assume that SO_2 is absorbed into the mesophyll water with no transport of SO_2 across cell boundaries. While the mesophyll water molecules are able to pass freely through cell membranes, SO_2 molecules are not. Translocation of SO_2 and ultimately its metabolism by the plant are far beyond the scope of this paper. We make two critical assumptions in order to estimate uptake of SO_2 . First we assume that the plant is able to metabolize all of the SO_2 it receives in the course of a day. Thus $X_0 = 0$ at the start of each new day. Secondly, the plant is not able to exchange SO_2 outside the mesophyll tissue rapidly enough to dilute the concentration resulting from SO_2 solubility. In calculations described more fully in the next section, the time scale to reach solubility is on the order of 2 hours. Clearly, our uptake estimates will be conservative unless the time scale for the plant to translocate SO_2 is

greater than 24 hours. Since it is more likely on the order of 6 hours, one might expect uptakes during the growing season to be greater by a factor of 2 to 3.

Two final assumptions, which relate to the neglect of radiation and water stress in our considerations, need explanation. These assumptions are justified on the basis of climatology of the locations and the physiology of the plants considered. In all but the worst cases of water stress, it seems likely that grass stomates will be open for the minimal amount of time (2 hr.) required to reach saturation. Studies of grasses further indicate that maximum stomatal opening occurs within about one hour after sunrise (Meidner and Mansfield 1968).

RESULTS

The model was applied to calculate sulfur dioxide uptake on a statewide basis for the Northern Great Plains. Ambient SO_2 concentration values were calculated using a simple long-range transport concept (Fox 1976). The model uses statewide estimates of climatology to determine parametric estimates of dry deposition and precipitation removal. Emissions were based upon (a) the "reasonable" development scenario for the year 1985 from the NGPRP (EPA 1974), and (b) the maximum development scenario for the year 2000 (EPA 1974). The entire state area is treated as being under natural vegetation -- range grasses. Vegetative uptake was calculated using the model described in the previous section. Climatological inputs were used for temperature and wind speed, and the ambient concentration was assumed to remain fixed at the calculated level.

A statewide value of leaf area index was determined in order to generate a statewide uptake estimate. Uptake was calculated using equations (1) - (5). Uptake estimates are summarized in Table 1, along with calculated concentrations and dry deposition estimates from the long-range transport (atmospheric) model. Values of the percent of deposited SO_2 that is taken up by vegetation are reasonable when related to the amount of vegetative cover and other uptake estimates for grasses (Spedding 1969). Obviously, estimates for statewide areas vary greatly with leaf area index, since a very large land area is involved.

Accuracy of the area estimates would improve if somewhat smaller, more vegetatively homogeneous surface areas were used. In addition to providing a general guide to a large area uptake, the SO_2 uptake model can also be used in a more refined calculation to provide vegetation removal boundary conditions

TABLE 1.

SULFUR DIOXIDE UPTAKE BY VEGETATION GIVEN ON A STATE BY STATE BASIS

STATE	AMBIENT CONC.		DRY DEPOSITION		UPTAKE (VEG.)		PERCENT REMOVED		VEGETATIVE UPTAKE AS A PERCENT OF DUH
	1985	2000	1985	2000	1985	2000	1985	2000	2000
	$\mu\text{g}/\text{m}^3$		kg/state/day		kg/state/day		BY VEGETATION		
MONTANA	4.46	6.7	45.7	68.7	1.0	1.5	2.1%	2.2%	14%
WYOMING	3.6	6.0	9.6	14.4	0.6	1.0	6%	6.9%	11%
NEBRASKA	3.3	4.9	7.8	11.5	0.4	0.6	5%	5%	11%
NORTH DAKOTA	10.2	16.4	12.8	20.5	1.9	3.0	15%	15%	38%
SOUTH DAKOTA	2.7	4.9	2.0	3.5	0.4	0.8	20%	23%	8%

for diffusion modeling.

Perhaps the most immediate use of the model is to provide a link between laboratory chamber studies and the real world environment. To this end, the model was run using environmental data from chamber studies (Hill 1973) and physiological damage data on alfalfa (Hanson 1972). Alfalfa was chosen for the test since it is both a sensitive species and one that may be used in the NGPRP to revegetate mined surfaces.

Chamber conditions were approximated with a ventilation speed of 2.5 m/sec, a temperature of 23°C, and an ambient SO_2 concentration of 500 $\mu\text{g}/\text{m}^3$. Vegetation damage in the chamber had been observed within a month with a 4-hour-per-day exposure. Our model -- equations (1) - (5) -- was run with these environmental conditions and indicated that saturation concentration, X_{sat} , in the mesophyll was reached well within the 4 hours each day (in fact, within about 1 hour). The daily uptake so calculated was multiplied by 30 to give a monthly estimate.

Since damage was observed in the chamber, we assume that this amount of SO_2 uptake is sufficient to produce damage, at least for alfalfa. We will term this the damage uptake horizon (DUH). The DUH is approximately 48×10^{-8} μg per cubic centimeter of mesophyll water. The ratio of actual uptake to DUH is shown in Table 1.

To consider a single "worst case" we chose North Dakota vegetative and atmospheric estimates for the year 2000. An ambient concentration of 16 $\mu\text{g}/\text{m}^3$ was taken following Fox (1976) for the maximum year 2000 scenario. Temperature was held constant at 6°C, as was the wind speed at 10 m/sec. The results of this calculation indicate that SO_2 uptake after 5 months is approximately 18×10^{-8} μg per cc of mesophyll water. While the ambient concentration between North Dakota and the environmental chamber differs by a factor of 30, uptake differs only by a factor of 2.5. This suggests that chamber studies may not be conservative in comparison with "worst case" environmental conditions.

CONCLUSIONS

The model presented here is a combined theoretical and empirical calculation which has not been fully validated. The individual equations have been validated, however. The use of the resistance analog, for example, is generally accepted.

Assumptions are made about many of the vegetation parameters, particularly for large area extrapolation and comparison with chamber studies. These may result in model estimates which are in error. In addition, sulfur

dioxide incorporation into the metabolic pathway represents the true removal mechanism, but it is not included in the present model. The problem of determining damage uptake horizon is extremely complex, since it depends on the sulfur status of plant and soil, and vegetation growth rates. For example, the difference in SO_2 uptake between the chamber and North Dakota vegetation may not be significant if coupled with information on sulfur status of the soil. The need for a soil model is evident.

The potential for vegetative removal of harmful pollutants has not been thoroughly explored. Murphy et al. (1975) have suggested that forests may have the potential to safely remove sulfur dioxide at low ambient concentration -- less than their damage threshold -- but the maximum level at which vegetation can safely remove pollutants is unknown (Neuberger 1963).

The model developed here is linear. It can accommodate additional input as information becomes available. The output yields information on regional vegetation uptake for sulfur dioxide. While it is clear that the development scenarios for the Northern Great Plains will add significant amounts of SO_2 to the ecosystem, we can not as yet provide any quantitative assessment of the effects. The model presented herein represents one of many steps toward this end.

REFERENCES

Chamberlain, A.C. 1966. Transport of gases to and from grass and grass-like surfaces. *Proc. Roy Soc. A* 290, 236.

- Environmental Protection Agency. 1974. Northern Great Plains Resources Program Accomplishment Plan, Region VIII, Appendix A to Region VIII, FY-75. Comprehensive Energy Accomplishment Plan.
- Fox, D.G. 1976. Modeling atmospheric effects -- an assessment of the problems. *Int. J. of Soil, Water and Air Pollut.*
- Johnstone, H.E. and P.W. Leppa. 1934. The solubility of SO_2 at low partial pressures. *J. Am. Chem. Soc.* 56, 2233-2238.
- Hanson, C.H. 1972. Alfalfa Science and Technology. American Society of Agronomy.
- Hill, A.C. 1971. Vegetation as a sink for atmospheric pollutants. *J. Air. Pollu. Contr. Asso.* 21.
- Meidner, H. and T.A. Mansfield. 1968. *Physiology of Stomata*. McGraw-Hill: Great Britain. 128 p.
- Murphy, B.D. 1976. Deposition of SO_2 on ground cover. In: *Proc. Amer. Met. Soc. Third Symp. on Atmospheric Turbulence, Diffusion and Air Quality*. Oct. 1976, Raleigh, N.C.
- Murphy, C.E., T.R. Sinclair and K.R. Knoerr. 1976. A model for estimating air pollutant uptake by forests. In: *Proc. Conf. on Metropolitan Physical Environment*, USDA Forest Service Northeastern Forest Exp. Stn., Upper Darby, PA.
- Neuberger, H. 1963. Vegetation as an aerosol filter. In: *Proc. of the Third Internat. Congress, Biometeorology II*, New York.
- Nobel, P. 1974. *Intro. to Biophysical Plant Physiology*. W.H. Freeman and Co. 488 p.
- Spedding, D.J. 1969. Uptake of sulfur dioxide by barley leaves. *Nature*, 224.

Sensitivity Analysis of Surface Deposition in a Numerical Model of Atmospheric Dispersion¹

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Abstract.--Profiles of height-dependent diffusion which accommodate site-specific diffusivities were produced. A numerical model was adapted to incorporate the profiles. The model represented three-dimensional steady-state advection and diffusion of aerosols from an elevated point source. Sorption effects were simulated with surface attachment coefficients greater than unity. This proved effective in depleting the plume differentially upward from the surface.

INTRODUCTION

Atmospheric dispersion models have been developed and refined in several forms over the past two decades, due to increased aerosol production and a heightened concern over the toxic effects of some aerosols on humans, animals, and plants. The models generally represent solutions of a differential equation which contains terms for advection and diffusion. The more basic solution in common use is the plume model, with a number of restrictive assumptions on atmospheric conditions.

The atmospheric turbulence near the ground differs significantly from the meso-scale eddy turbulence usually used for dispersion calculations (Pasquill 1974). Sutton (1953) recognized that constant eddy diffusivity is unacceptable in problems of diffusion in a turbulent atmosphere. Dispersion coefficients depend upon, among other factors, height above the surface, surface roughness, the scale of motion, and wind speed and fluctuations (Agee, et al. 1973). Diffusivity cannot be treated independent of height above the ground if the boundary layer flow in the first several hundred meters is to be repre-

sented. There exists no convenient method for determining the relationship between the aerodynamic roughness of the surface and the dispersion coefficients (Ragland and Dennis 1975). Estimates of diffusivities from Pasquill stability categories only give crude indications of the diffusion characteristics (Reiter 1973). Lettau (1973) concluded that eddy diffusivities are generally unique to any given experimental situation and have very little extrapolative value to other experimental situations.

Using superpressure mylar balloons, measurement of lateral and vertical diffusivities as functions of height can be made. From the tracking data, the coefficients are calculated as functions of the variance of the Lagrangian velocity components and Lagrangian time constants. Wooldridge and Orgill (1975) used this technique in the Eagle River Valley of Colorado. Wooldridge (1974) determined height profiles of diffusivities in Cache Valley of northern Utah from balloon data. Computations using measured diffusivities profiles for these two valleys showed concentration distributions quite different from each other (Wooldridge and Lewis 1975). Circulation separation between Cache Valley and the gradient wind above ridge lines was found by Ellis and Wooldridge (1973). Studies of diffusivities in valleys by Wooldridge (1974) and Wooldridge and Orgill (1975) demonstrate increasing K values throughout the valley to just above the ridge. This indicates that the entire valley is within the surface boundary layer and that the diffusivities probably decrease in the gradient flow above this point.

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The general shape of the vertical distri-

bution of diffusivity shows a local maximum of the diffusivity, K , near the top of the surface boundary layer (Blackadar 1962; Agee, et al. 1973; Egan and Mahoney 1972; Wipperman 1973; O'Brien 1970). The following exponential function was developed by Agee, et al. (1973),

$$K(z) = a[\exp(-bz/Z_T) - \exp(-bcz/Z_T)] \quad [1]$$

where a , b , and c are arbitrarily chosen parameters that primarily affect the magnitude of K , the height scale, and the ratio of the maximum diffusivity to the diffusivity at the top of the Ekman layer, respectively. Z_M is the height of the maximum diffusivity, Z_T is the top of the Ekman layer, and z is the height above the surface.

When c is greater than one in equation [1], as Agee, et al. said it should be, the resulting profile increases rapidly near the surface, changes more slowly as the top of the surface boundary layer is approached, then decreases upward. Wooldridge and Orgill (1975) measured diffusivity profiles in mountainous terrain that increased slowly near the surface and more rapidly from the middle to the top of the valley. Profiles that behave this way in the surface boundary layer can be produced with Agee's formulation if c is less than one. However, these profiles will not decrease above the surface boundary layer. Steady-state calculations within the valley, as in this study, are not affected by the shape of the profile above the valley.

A variety of processes remove aerosols from the atmosphere, although they are incompletely understood. Deposition by precipitation scavenging accounts for some removal, but it occurs infrequently in arid regions. Reaction, or sorption, with the soil or plants probably removes the largest percentage and should be considered as a major sink. The physics of particle-surface interactions is quite complicated. Natural surfaces may be good reflectors or good adsorbers, but rarely perfect. The exact behavior at the interface depends upon the properties of the surface and the diffusing particles (Csanady 1973).

Depending on the vegetation type, the area of leaf surface per unit area of ground may vary from a factor of two to a factor of ten. The cellular surface area surrounding the intercellular air spaces within the leaf is considerably higher than the leaf surface area (Hill 1971). Therefore, the effective adsorbing surface may be many times greater than the total surface area. Slade (1968) reported that Simpson (1961) computed deposition of 90% within 3200 meters of the source. Martin and Barber (1971) found a reduction of

75% in SO_2 between 15 and 50 cm above a hedge. Hill (1971) measured uptake of CO_2 and O_3 by alfalfa and oats in a laboratory chamber and in the field. He found it to vary from 86% to 95% depending upon the wind speed, canopy, and light. On soil with no plants the uptake was only 7% for dry soil and 19% for wet soil.

PROCEDURES

The starting point of most mathematical treatments of diffusion from sources is a generalization of the classical differential equation of heat conduction in a solid. Roberts (1923) gave the solution for the steady-state continuous point source as

$$\frac{\chi}{Q}(x,y,z) = \frac{1}{4\pi x(K_y K_z)^{1/2}} \exp \left[\frac{-\bar{U}}{4x} \left(\frac{y^2}{K_y} + \frac{z^2}{K_z} \right) \right], \quad [2]$$

where Q is the source strength, χ is the local concentration, x , y , and z are rectangular coordinates (along-wind, crosswind, vertical), K_y and K_z are the crosswind and vertical diffusivity coefficients, respectively, and \bar{U} is the mean wind speed. The current plume models now in use substitute $\sigma^2 = 2Kt$, where t is time and σ^2 is variance of an assumed Gaussian distribution, in the above equations resulting in diffusion dependent upon downwind distance and independent of height.

The mathematical device which represents perfect reflecting boundaries is the introduction of "mirror-image" sources of strength equal to the source at its origin (Csanady 1973). Surface attachment is parameterized by multiplying each reflective term of the equation by $(1-\alpha)$, where α is an attachment coefficient. Using height-dependent diffusivities as determined by equation [1], assuming an incompressible fluid and neglecting diffusion along the wind, the equation for an elevated source becomes:

$$\begin{aligned} \frac{\chi}{Q}(x,y,z) = & \frac{(K_y(z)K_z(z))^{-1/2}}{4\pi x} \left[\exp \left(\frac{-\bar{U}y^2}{4xK_y(z)} \right) + \right. \\ & (1-\alpha) \left\{ \exp \left(\frac{-\bar{U}(2C+y)^2}{4xK_y(z)} \right) + \exp \left(\frac{-\bar{U}(2B-y)^2}{4xK_y(z)} \right) \right\} * \\ & \left. \left[\exp \left(\frac{-\bar{U}(z-h)^2}{4xK_z(z)} \right) + (1-\alpha) \exp \left(\frac{-\bar{U}(z+h)^2}{4xK_z(z)} \right) \right] \right], \quad [3] \end{aligned}$$

where B and C are the distances from the source to the farthest and closest valley walls, respectively. Figure 1 illustrates the mirror-image reflection from the surface and the two valley walls.

The topography simulated for this study

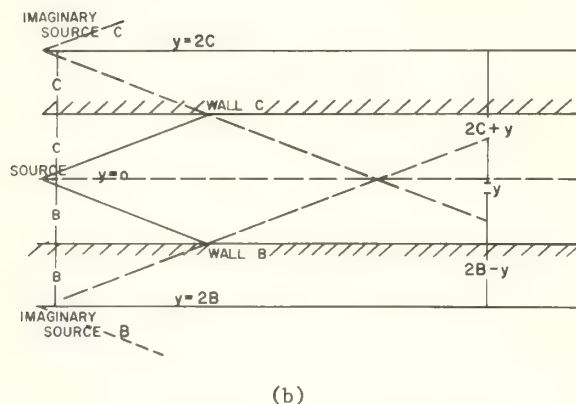
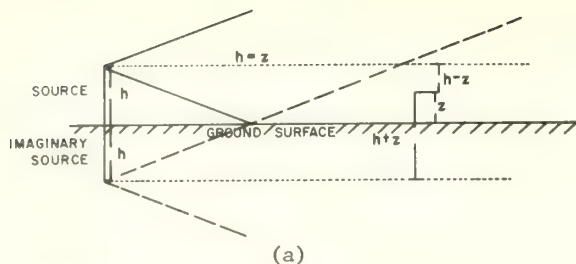


Figure 1. Simulated topography and ideal plume position for a continuous point source in a mountain valley. (a) side view, (b) top view.

was a long, narrow, symmetric valley with steep, sloping sides. The sloping walls were approximated in a step-like mode by increasing the distance from the valley center ($y = 0$) to the walls for each increase in height according to:

$$B = Y_t - B_t + z/\tan\phi. \quad [4]$$

The slope of the walls, ϕ , was 30° from horizontal; B_t is the distance from the source to the B wall at the top of the valley. Valley symmetry here allowed C equal to B. At ridge height ($z = 1000$ m) the half width of the valley, Y_t , was 2500 m. The valley floor was 767 m wide, flat and non-sloping. There were no obstructions to airflow within the valley as far as the calculations proceeded. A continuous point source was simulated 100 m above the ground and in the center of the valley. The mean wind along the valley was taken at 3 m sec^{-1} . All ground surfaces were assumed to be covered with vegetation.

For each diffusion profile a set of the constants a , b , and c is required. Agee, et al. (1973) obtained a solvable system for determining a , b , and c when the values of Z_M , Z_T , the maximum diffusivity, K_M , and the dif-

fusivity at the top of the profile, K_T , are known. The height of the maximum diffusivity, Z_M , is taken to be above the ridge height at 1200 m, considered to be the top of the surface boundary layer. Because the top of the Ekman layer is likely to be found in a zone around twice the ridge height, 2400 m was taken as the top of the profile, Z_T , for this model. Values of a , b , c , K_M , and K_T are given in Table 1 for each of the diffusion profiles.

Table 1. Parameters for K_y and K_z profiles.

	K_{yI}	K_{zI}	K_{yII}	K_{zII}
a	2400.00	2000.00	-3559.00	4000.00
b	-1.95	-2.00	2.11	1.93
c	0.98	0.98	0.90	1.07
K_M	--	--	135.90	99.50
K_T	--	--	80.20	58.90

K_{yI} and K_{zI} represent the lateral and vertical diffusivities found in mountainous terrain while K_{yII} and K_{zII} are the profiles suggested by Agee, et al. The diffusivity profiles were obtained by calculating $K(z)$ at each computational height. Diffusion at the surface was not allowed to go to zero as in equation [1]. The diffusivity was assumed to be constant from $z = 10$ m to the surface and equal to the value at 10 m. The diffusivities fit well into the range of the Pasquill estimations, and the resulting profiles are shown in Figure 2.

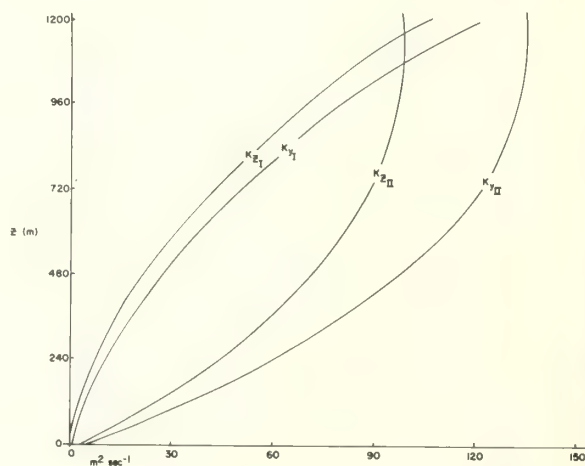


Figure 2. Diffusivity vs. height. K_z --vertical--component; K_y --horizontal component. Case I and Case II (refer to Table 1).

A perfectly reflecting boundary can be represented by equation [3] with $\alpha = 0$. At any given point in the grid the reflected amount represents a smaller percentage of the total concentration than the amount contributed by the original source. With $\alpha = 1$ there would be no reflection of plume material. The unreflected plume would still be within the surface layer and available for removal by the multiple-layered plant canopy. Further removal can be parameterized by increasing the value of α greater than 1. This would result in removal of not only the reflected amount, but some fraction of the original plume. Values of α between 0 and 1.5 were used in this study. The vegetation on all surfaces was assumed to have similar adsorption capabilities.

RESULTS AND DISCUSSION

The diagrams of normalized concentrations, figures 3-8, reveal a dramatic change in pattern when the profile suggested by Agee, et al. (1973) (case II) is modified through the use of b less than zero and c less than one. The plume centerline is no longer depressed toward the surface but remains near the original source (effective stack) height for distance up to or exceeding 10 km in a mountain valley. Further, the plume of case I does not spread laterally as quickly at low levels, due to the smaller values of K_{yI} computed there, while the case II plume is quite evenly distributed.

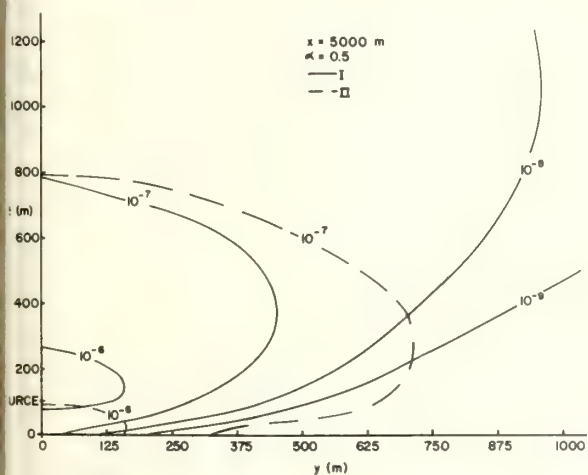


Figure 3. Isopleths of concentration. 5000 m downstream. $\alpha = 0.5$.

The diffusivity profiles used in the case I calculations more closely fit the profiles measured at Camp Hale, in the Rocky Mountain plateau of central Colorado (Wooldridge and Orgill 1975). Plume tracking by aircraft also

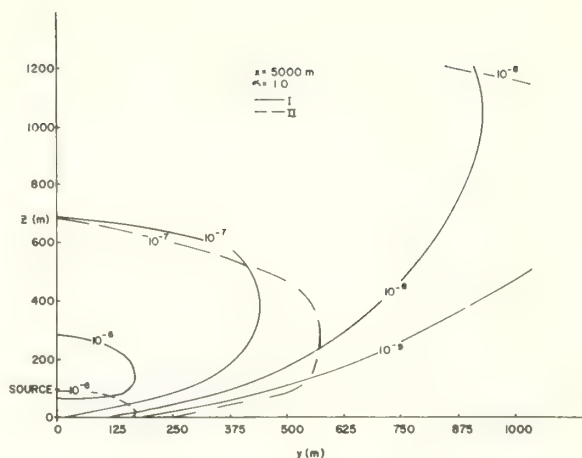


Figure 4. Same as 3 except $\alpha = 1.0$.

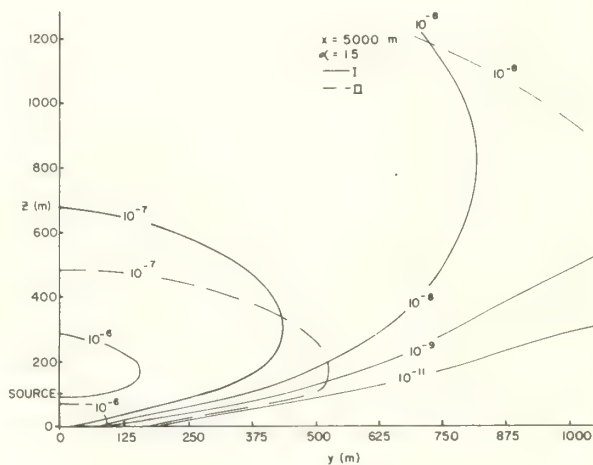


Figure 5. Same as 3 except $\alpha = 1.5$.

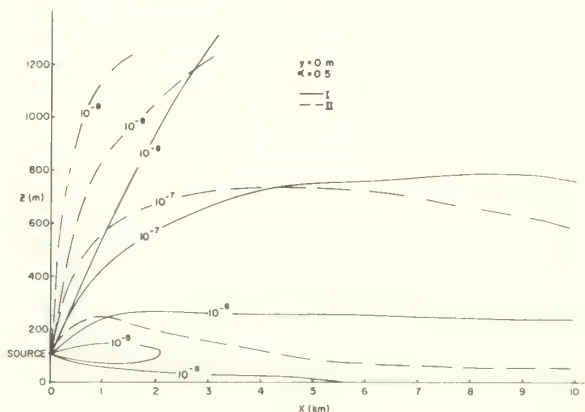


Figure 6. Isopleths of concentration along centerline. $\alpha = 0.5$.

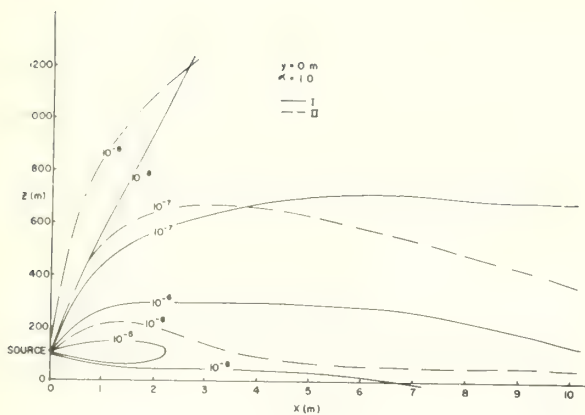


Figure 7. Same as 6 except $\alpha = 1.0$.

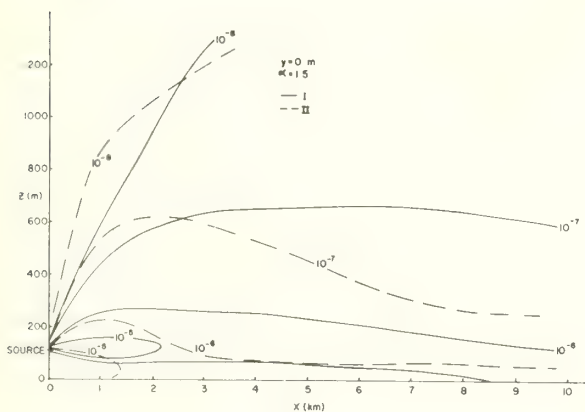


Figure 8. Same as 6 except $\alpha = 1.5$.

suggests that the lowering of plume centerline as calculated with b greater than zero and c greater than one does not occur, either in mountain valleys or over less rugged terrain. Dispersion is better represented by site-specific diffusion than a generalized formulation.

The patterns of both sets of calculations change as the attachment coefficient, α , varies from partial attachment ($\alpha < 1$) to greater than unity. Near the source where the reflective terms have no influence the attachment coefficient makes little impact in the distribution. In the remaining airspace the attachment coefficient is most effective where the diffusion is greatest. Figures 3, 4 and 5 reveal a gradual decrease in the concentration of aerosols at the surface and in the airborne plume as α increases, with a greater effect in case II (note the change in the 10^{-7} isopleth). When α

increases beyond one (Figure 7) the concentration near the ground toward the valley walls decreases by two orders of magnitude. The longitudinal sections (Figures 6, 7, and 8) also illustrate the effects of increasing α to higher values, with the concentration near the ground decreasing the most noticeably downwind from the source.

CONCLUSIONS

The practice of allowing an attachment coefficient to attain values greater than unity appears to simulate the enhancement of surface sorption by foliage, reducing aerosol concentrations in the plume well above the surface. The sensitivity of the model to attachment seems somewhat dependent upon the rate of the diffusion. This method should be further tested using field tracer experiments to determine appropriate values of α for various atmospheric conditions and foliage types, but this study suggests the feasibility of the technique for operational and investigative purposes.

The variation of aerosol concentration patterns as the diffusivity profile is changed emphasizes the significance of this factor in plume modeling for this study. The magnitude of the diffusivities at the top of the boundary layer, here estimated to occur slightly above the mountain ridge line, were approximately the same. The major difference in the two sets of profiles was the curvature within the valley (surface boundary layer). This stresses the need for more measurements of site-specific diffusivity profiles, particularly in rough terrain, before adequate dispersion modeling can be accomplished. The shape of the profile and the magnitude of the diffusivities must be determined over a range of meteorological regimes.

LITERATURE CITED

- Agee, E. M., D. E. Brown, T. S. Chen, and K. E. Dowell. 1973. A Height Dependent Model of Eddy Viscosity in the Planetary Boundary Layer. *Jour. App. Meteor.* 12(2):409-412.
- Blackador, Alfred K. 1962. The Vertical Distribution of Wind and Turbulent Exchange in a Neutral Atmosphere. *Jour. of Geophys. Res.* 67(8):3095-3101.
- Csanady, G. T. 1973. *Turbulent Diffusion in the Environment*. D. Reidel Publ. Co., Boston. 248 p.
- Egan, Bruce A. and James R. Mahoney. 1972. Numerical Modeling of Advection and Diffusion of Urban Area Source Pollutants. *Jour. Appl. Meteor.* 11(2):312-321.

- Ellis, Ronan I. and Gene L. Wooldridge.
1973. Atmospheric Dispersion Characteristics of a Northern Utah Mountain Valley. Dept. Soils and Biomet. Tech. Paper No. 2. 57 p.
- Hill, Clyde A.
1971. Vegetation: A Sink for Atmospheric Pollutants. Jour. Air Poll. Cont. Assoc. 21(6):341-346.
- Lettau, Bernhard.
1973. Eddy diffusion coefficients in the stable surface layer. Tellus. XXV(4): 374-380.
- Martin, A. and F. R. Barber.
1971. Some Measurements of Loss of Atmospheric Sulphur Dioxide Near Foliage. Atmos. Envir. 5(5):345-352.
- O'Brien, James J.
1970. A Note on the Vertical Structure of the Eddy Exchange Coefficients in the Planetary Boundary Layer. Jour. Atmos. Sci. 27(8):1213-1215.
- Pasquill, F.
1974. Atmospheric Diffusion. 2nd Edition. John Wiley and Sons, New York. 429 p.
- Ragland, Kenneth W. and Robin L. Dennis.
1975. Point Source Atmospheric Diffusion Model with Variable Wind and Diffusivity Profiles. Atmos. Envir. 9(2):175-189.
- Reiter, Elmar R.
1973. Dispersion of Pollutants. G. L. Wooldridge and D. F. Peterson (Eds.). Proceedings from a Workshop on Inadvertent Weather Modification, Utah State University. p. 157-185.
- Roberts. O. F. T.
1923. The Theoretical Scattering of Smoke in a Turbulent Atmosphere. Proc. Roy. Soc. (London) 4:640-654.
- Simpson, C. L.
1961. Some Measurements of the Deposition of Matter and Its Relation to Diffusion from a Continuous Point Source in a Stable Atmosphere, USAEC Report HW-69292 REV, Hanford Atomic Products Operation. (Original not seen)
- Slade, David H. (editor).
1968. Meteorology and Atomic Energy. 1968 USAEC Division of Technical Information Extension, Oak Ridge, Tennessee. 445 p.
- Sutton, O. G. 1953. Micrometeorology.
1953. Micrometeorology. McGraw-Hill Book Co., Inc. New York. 333 p.
- Wipperman, F. K.
1973. Eddy Diffusion Coefficients in the Planetary Boundary Layer from Turbulent Diffusion in Environmental Pollution. F. N. Frenkid and R. E. Munn (eds.). Academic Press. New York.
- Wooldridge, Gene L.
1974. Atmospheric Dispersion Characteristics of a Large Mountain Valley. Presented to the Conference on Fire and Forest Meteorology held April 2-4, 1974, at Lake Tahoe, Nev. 16 p.
- Wooldridge, Gene L. and Jackie Lewis.
1975. Dispersion in Mountain Valleys Using Measured Constants in a Modified Plume Model. Presented at the 12th AMS Conference on Agriculture and Forest Meteorology, Tucson, Ariz. April 14-16, 1975.
- Wooldridge, Gene L. and Montie M. Orgill.
1975. Airflow and Diffusion in High Mountainous Terrain. Presented at the first AMS Conference on Regional and Mesoscale Modeling, Analysis, and Prediction. May 6-9, 1975, Las Vegas, Nevada. 21 p.

Experimental Studies of Herbicide Drift Characteristics¹

D. S. Renne and M. A. Wolf^{2/}

A field study, utilizing a unique experimental design which monitored all the various components of herbicide drift, was undertaken by Battelle-Northwest on the Hanford Reservation in eastern Washington State during 1975 to study techniques for maximizing herbicide applications from a spray airplane on the intended area and minimizing drift. The results of these experiments have shown that the initial drift and drift deposit components for various application techniques varied by only a factor of two or so, depending on the production of smaller droplets. Meteorological conditions become increasingly important at greater downwind distances from the source. Furthermore, drift reduction was most effective under conditions of high relative humidities and cool temperatures. At large distances from the source, ground level drift was higher on stable than on unstable days.

INTRODUCTION

The use of chemical herbicides and pesticides to control broadleaf weeds and insects in crops and forest stands has been given increasing application in recent years by agriculturalists and foresters. However, the potential damage to nearby sensitive crops or to humans from the inadvertent drift of these chemicals beyond the intended area of application continues to be a serious problem, and has been given extensive study. Tests conducted in Arizona, for example, show that in general less than 50% of the intended aerial application of a pesticide is actually deposited on the target (Ware, et al., 1970). Other researchers have found that the drift component is roughly 3% of the intended application for ground rigs, and as much as 4-5 times that amount for aerial applications (Drummond, 1973; Frost, 1973). Atmospheric measurements of 2,4-D have shown that drift can extend well beyond the target area. Levels averaging 0.3 to 0.6 g-m⁻³ have been maintained for periods on the order of a month in the wheat producing regions of Saskatchewan and Washington (Peckenpaugh, et al., 1974; Que Hee, et al., 1975).

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Numerous studies to determine techniques to reduce the drift component from aerial and ground-rig applications have been undertaken. These studies have shown that meteorological conditions, particularly atmospheric turbulence and the near-surface relative humidity and air temperature, greatly affect the drift component, with the larger drift residues observed under stable, dry atmospheric conditions (e.g., Yates and Akesson, 1966). These researchers have also experimented with a variety of nozzle configurations and spray viscosities and have shown that drift residues can be decreased by about a factor of two by attempting to eliminate the finer droplets and increasing the viscosity of the mixture (e.g., Kaupke and Yates, 1966). However, a major short-coming of most of these studies is that only one component of the drift, usually the drift residues or downwind depositions, was measured. Unless all material is accounted for as deposition, the drift component can not be determined without additional air concentration measurements, both along the surface downwind from the source and in the vertical.

Hypothesizing that all the components of drift (ground level and vertical exposure and surface deposition) need be measured simultaneously to determine effective drift control techniques, Battelle-Northwest conducted field experiments during the summer of 1975. All the components of various aerial applications of 2,4-D herbicide on target and down-

wind of the target area under differing environmental conditions and for a variety of spray nozzle configurations and herbicide concentrations were measured. The ultimate goal of experiments such as these is to utilize the information to optimize the use of 2,4-D so that effective weed control and substantial reduction in the drift component can be achieved. Although these experiments were designed primarily for agricultural applications, the results can be applied to forestry uses, where the characteristics of the drift component over a forest canopy from aerial applications of insecticides must be understood.

EXPERIMENTAL OBSERVATIONS

Experimental Site

The 2,4-D drift and deposition experiments were conducted at a site approximately 40 km northwest of Richland, Washington on the Hanford Reservation. This facility is operated by the United States Energy Research and Development Administration. The site is a portion of the Hanford diffusion grid, and is characterized by relatively flat, sagebrush covered land at an elevation of about 220 meters above sea level.

A permanent 62 meter tower on the Hanford diffusion grid was incorporated into the 2,4-D experimental site. This tower is 1600 meters to the east of the Hanford Meteorological Station (HMS) 125 meter tower, and 225 meters to the east of the spray aircraft flight path.

Field Equipment

The deposition of 2,4-D was sampled at 30 locations in the target area and at eight additional points downwind of the target area, including the tower location. Air samplers were also positioned at the same eight downwind points, with an additional nine samplers located at ten levels on the 62 meter tower.

The deposition jars in the target area were divided into two lines, one 20 meters to the north of the downwind array, and the other along the same line as the array. Each line of target area deposition samplers consisted of 15 jars located three meters apart. The eight downwind samplers were spaced 25 meters apart, with the first sampler located 25 meters downwind of the spray aircraft flight path. The vertical air samplers were spaced in a logarithmic fashion ranging from 0.39 to 62.0 meters above the ground. A schematic of the sampling array is shown in Figure 1.

The 1,500 meter flight path was oriented 18° from normal to the array. This was approximately normal to the predominant wind direction which, during the early morning hours of the summer season, is from 270° to 290°. The length of the flight path was chosen to assure that the tower samples were not subjected to the "edge effects" of the drifting cloud; i.e., they effectively would be sampling an infinite instantaneous line source.

Operations

A Piper Pawnee spray airplane was provided by the USDA Agricultural Research Service for this study. A unique feature of the aircraft was the capability to make two different applications of 2,4-D within a 5-minute period. This was possible because the aircraft is equipped with two separate systems of tanks, pumps and booms. This capability was utilized in this study by making a standard or "fixed" application from one system and a comparative or "test" application from the other. A single set of samples was exposed during the release and passage of both 2,4-D applications. They were quantified separately in the laboratory analysis phase. The meteorological conditions were assumed to be nearly identical for the two applications due to the short time period between releases. Thus significant observed differences in the drift between the two releases could be attributed principally to the spray nozzle configuration and the concentration of the chemical herbicide. Furthermore, comparison of the fixed application drift measurements for the several days helped identify and quantify the important meteorological effects.

Two commercially available low-volatile herbicides were chosen as tracers for this study, each of which can be quantified independently on a single sampler. The fixed application was 2.8 cc-m⁻² (3 gal-acre⁻¹) of water containing 30 mg-cc⁻¹ (0.25 lb-gal⁻¹) acid equivalent of a butoxyethanol ester (BE).

The tracer utilized to test various configurations was a propylene glycol butyl ether ester (PGBE). The intention was to release the PGBE from different types of nozzles and with different concentrations to provide information on which application techniques reduced the drift component.

Four experiments, conducted in the daylight hours prior to 0700 PDT, under conditions of light winds, are studied here. Table 1 provides information on these tests, including the important differences between each of the PGE test applications and the BE fixed application.

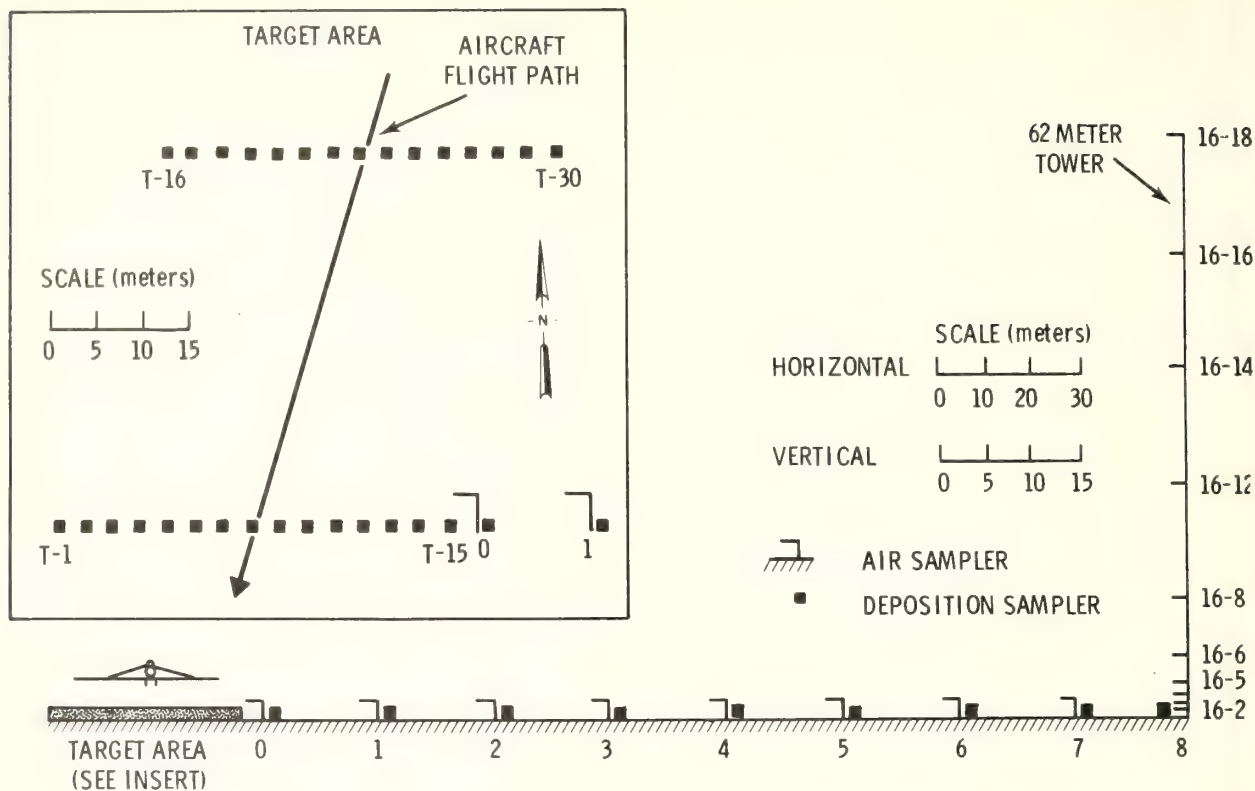


Figure 1. Schematic of Runs 5 - 7 Experimental Array

Table 1. Summary of 2,4-D Drift Experiment Tests

Run	Date	Local Time	Varations in Nozzle Configuration and Concentrations from Fixed Application
1	July 10	0650	None
2	Aug. 19	0622	Application rate: 1 gal-acre ⁻¹ (0.93 cc-m ⁻²) 25 nozzles, type D5/45
3	Sept. 3	0640	Application rate: Same as control 35 nozzles, type D5/no core; attitude angle 135° back (downward)
4	Sept. 16	0647	Application rate: 5 gal-acre ⁻¹ (4.7 cc-m ⁻²) 31 nozzles, type D8/46

All four runs were designed to compare various drop size spectrums caused by variations in operational techniques: low volume application per acre (Run 2), no swirl plate and steeper nozzle angle (Run 3), and high volume application per acre (Run 4).

RESULTS

Ground Level Drift

Figures 2 and 3 show distributions of ground level drift downwind of the source for the fixed and test application, respectively. Least squares lines of best fit were computed for each run and are included in the figures. In addition, a stability factor, F , was defined, following previous investigations (Yeo and Thompson, 1953):

$$F = \frac{T_{15} - T_2 - \Gamma \Delta H}{\bar{u}^2} \quad (1)$$

where: T_{15} = temperature at 15 meters above the ground, °C

T_2 = temperature at 2 meters above the ground, °C

Γ = dry adiabatic lapse rate = -0.01 °C-m $^{-1}$

ΔH = distance between upper and lower temperature levels, m

\bar{u} = mean wind speed between 2 and 15 meters above the ground, m-sec $^{-1}$.

The stability factors were computed from the HMS tower data at the time of the herbicide releases. A negative factor indicates an unstable atmosphere, and a positive factor a stable atmosphere.

Figure 2 shows that application of the same herbicide tracer applied in an identical manner on different days differed greatly due to different meteorological conditions. There are large differences in the slopes occurring for the cooler, more humid days when the droplets experience less evaporation and fall out faster, thus depleting the drifting plume. If these lines were to be extrapolated to distances well beyond 200 meters, then it is evident that large differences in drift would occur for different meteorological conditions.

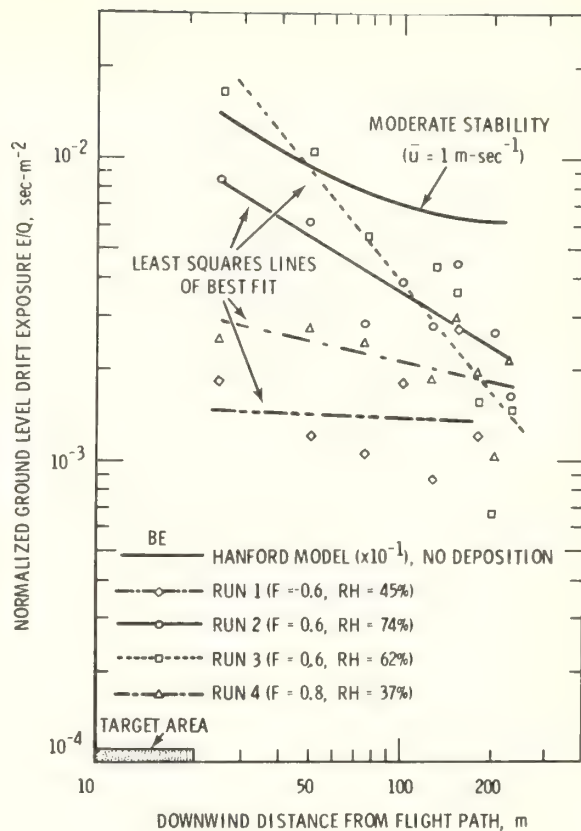


Figure 2. Normalized Ground Level Drift Exposures vs. Downwind Distance from Flight Path, Fixed Application of BE.

The test application drift characteristics shown in Figure 3 do not coincide with those of the fixed application. This is due to the effect of the differences in the way the PGBE ester was released from the spray aircraft. But again the slopes of the lines become the dominating influence in displaying drift reduction beyond 200 meters, indicating the importance of meteorological conditions in controlling drift. The different mechanical techniques tested to control drift resulted in variations of only a factor of two or so in the drift component. This is well within the sampling accuracy limitations of the experiment. However, the differences in slopes of the drift characteristics patterns between warm, dry days and cool, moist days result in substantial differences in ground level drift at large distances from the source. Thus, beyond 200 meters from the source meteorological conditions appear to be the dominant factor in controlling drift, and the manner in which the material is released from the aircraft, although still important, becomes a

Drift Deposits

Figures 4 and 5 show the distribution of downwind drift deposits normalized to the aircraft release rates for Runs 2 through 4 (drift deposits were not obtained for Run 1). The fixed application drift deposits for Runs 2 and 3, which were cool, moist stable days, show striking similarities to each other, and beyond about 75 meters from the source show substantially less drift deposits than Run 4, which was a warm, dry day. Again this indicates the significance of meteorological conditions for controlling drift deposits, particularly at the larger distances from the source.

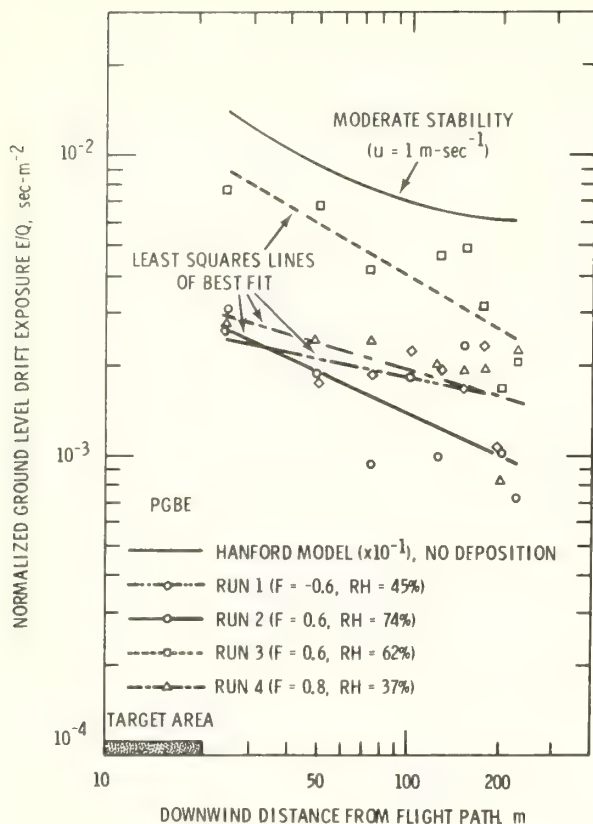


Figure 3. Normalized Ground Level Drift Exposures vs. Downwind Distance from Flight Path, Test Application of PGBE.

secondary factor. In particular, drift reduction is best on cool, moist days when evaporation of the droplets is minimized and their fallout at distances within 200 meters from the source is facilitated.

A curve representing the Hanford diffusion model for moderately stable conditions with 1 m-sec⁻¹ wind speeds and an aircraft height of 5 meters above the ground is included in the figures. This model is representative of a nondepositing instantaneous infinite line source plume and is discussed in detail by Slade (1968).

In Figures 2 and 3 the curves of the Hanford model have been reduced by a factor of ten to coincide roughly with the actual drift characteristic values. When comparing the slopes of the nondepositing theoretical curve with those of the depositing observed drift characteristics, it is evident that deposition is much higher on cool, moist days when evaporation of the droplets is suppressed.

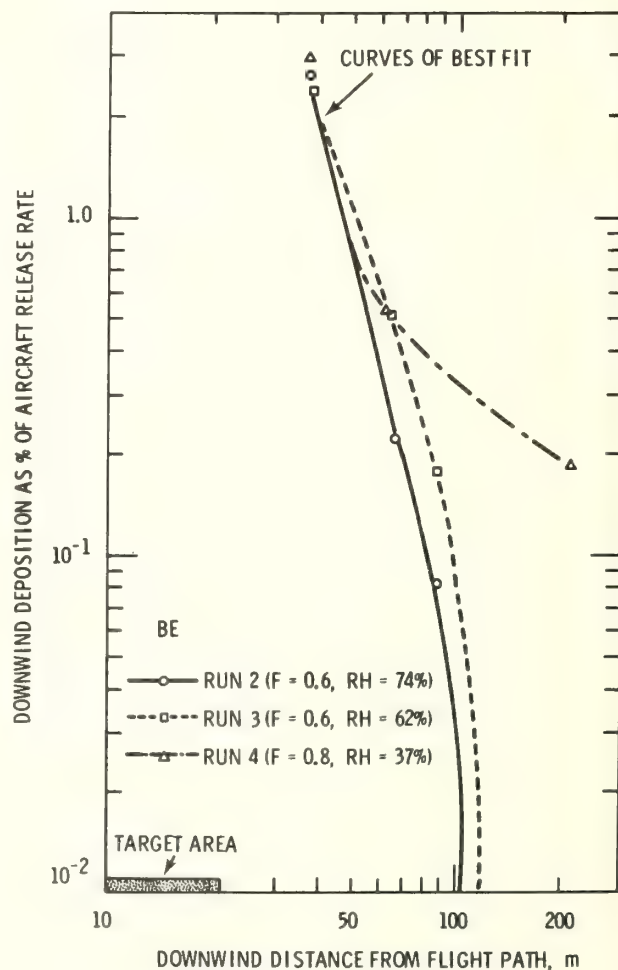


Figure 4. Normalized Drift Deposits vs. Downwind Distance from Flight Path, Fixed Application of BE.

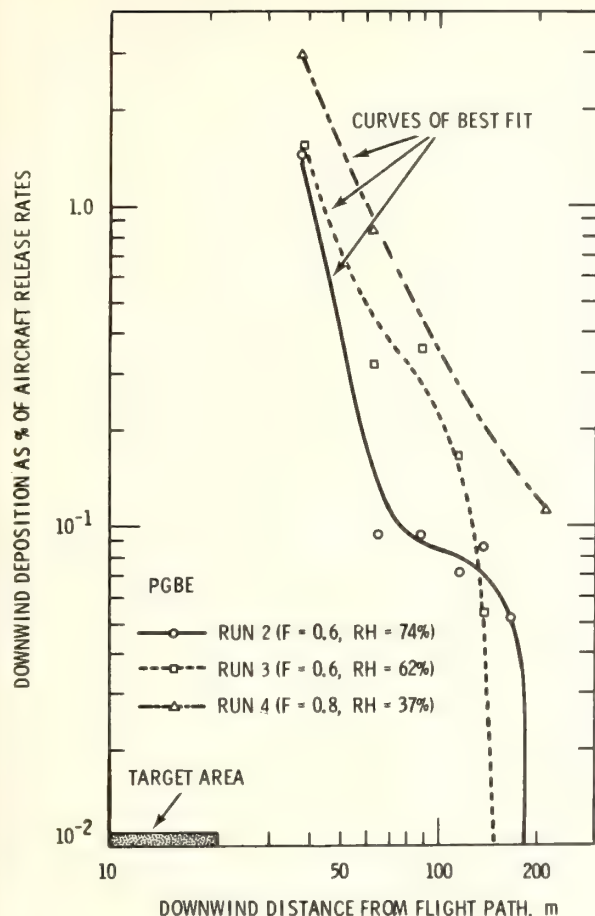


Figure 5. Normalized Drift Deposits vs. Downwind Distance from Flight Path, Test Application of PGBE.

The drift deposit characteristics for the test applications are similar to the fixed applications with the exception of a delayed deposition indicated by the slight "humps" in the curves between 75 and 100 meters for Runs 2 and 3. This delayed deposition can be due to a slightly different droplet size distribution from the fixed application technique, indicating the effect of different mechanical modes for releasing the material. Since these two runs were on cool, moist mornings, less evaporation is occurring and the smaller droplet spectrum that results in this delayed deposition characteristic is not suppressed. Run 4, which was a warm, dry morning, suggesting greater evaporation, does not show this characteristic, indicating that the smaller droplets have already evaporated. Nevertheless, drift deposits are higher in general for that day since the total drift is higher.

These curves suggest a bimodal type of droplet size distribution resulting from the various types of release of the herbicide. The primary distribution consists of the larger droplets, the size that are produced purposefully to assure application of the herbicide on the intended area. However, a secondary distribution results from the breakup of the solution as it is released and from evaporation of the larger drops. This distribution consists of finer particles whose fallout is delayed due to lower settling velocities. Figures 4 and 5, as well as Figures 2 and 3, suggest that this droplet size spectrum can be controlled somewhat by the manner in which the herbicide is released from the aircraft, but that beyond 100 meters or so meteorological conditions become the primary influence on drift and drift deposit characteristics.

Deposition Velocities

Although the same conclusions can be drawn from the analyses in each of the previous two sections, some question remains as to the effectiveness of determining total drift from deposition samplers alone, as previous investigators have attempted. The evidence from Figures 2, 3, 4 and 5 indicates that air samplers are much more sensitive to drift than deposition jars for the release rates used here, and therefore provide more complete definition of the ground level drift. But more quantitatively, determining drift characteristics from deposition measurements requires knowledge of the relationship between drift and deposition. If this relationship is constant, inference on drift characteristics from deposition measurements can be made with reasonable certainty. However if the relationship between these two parameters is variable, characteristics of drift can be inferred erroneously from deposition measurements.

The relationship between drift and deposition can be expressed in terms of the deposition velocity:

$$V_d = 100 \left(\frac{D_f}{E} \right) \quad (2)$$

where: V_d = deposition velocity, cm-sec⁻¹
 D_f = deposition flux, g-m⁻²
 E = ground level air exposure, g-sec-m⁻³.

Deposition velocities were computed from the drift and deposition data obtained in Runs 2 through 4 and are shown in Figure 6 for the BE releases and Figure 7 for the PGBE releases. The deposition velocity characteristics are

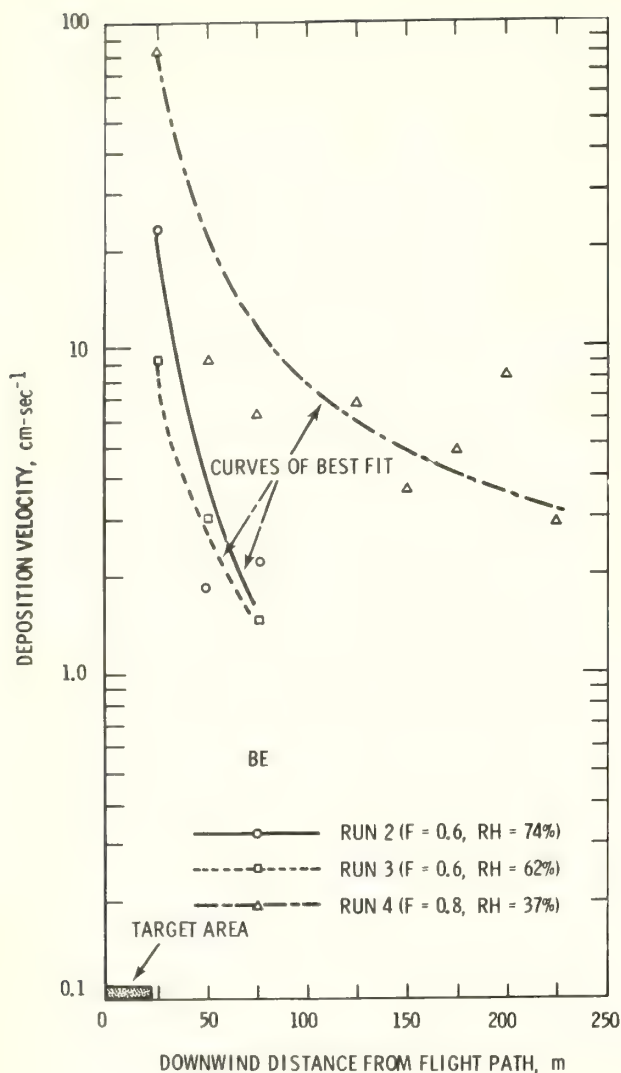


Figure 6. Downwind Deposition Velocities, Fixed Application of BE.

highly variable within 200 meters of the source, indicating the presence of a significant amount of larger droplets in the drift downwind of the target area. Thus for the size of the array used in these experiments inferring drift from deposition alone could result in erroneous conclusions with regard to methods to control drift.

The curves also show that once a sufficient distance is reached from the source the deposition velocity would probably reach a steady-state value of approximately 1 cm-sec^{-1} . This value appears reasonable in light of other investigations undertaken on the Hanford Reservation (Slade, 1968).

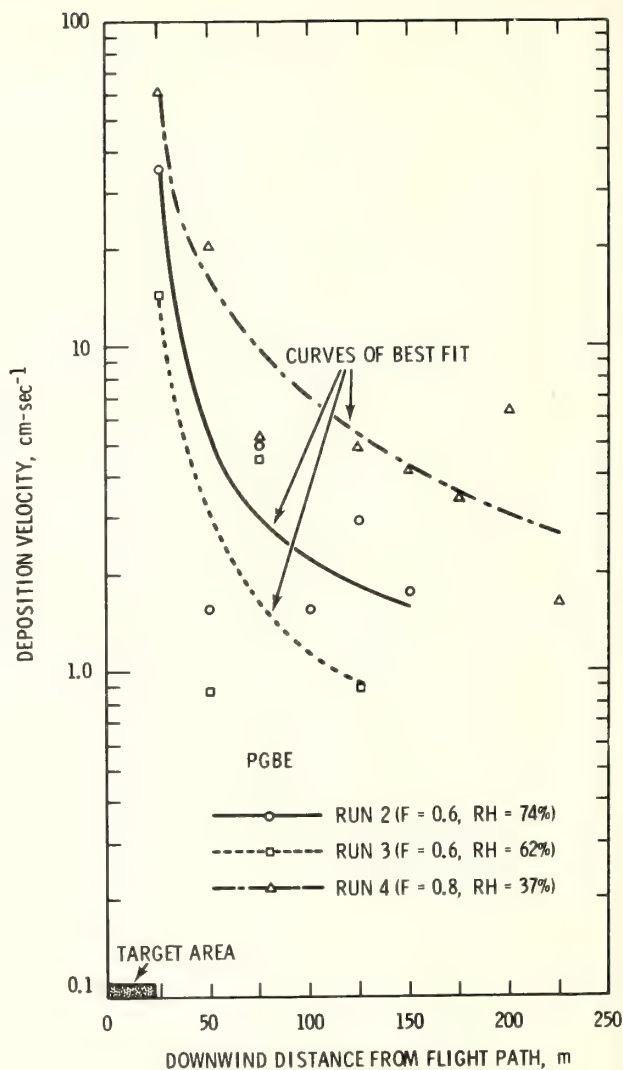


Figure 7. Downwind Deposition Velocities, Test Application of PGBE.

CONCLUSIONS

A number of different hypotheses with regard to reducing herbicide drift from spray airplanes using various nozzle sizes and orientation, and by spraying under different environmental conditions, have been tested under a pilot field experiment in eastern Washington. Although the results of these tests can only be regarded as preliminary until a more complete set of experimental information has been obtained, the major conclusions of these experiments are:

1. The combined deposition and air sampler approach is superior because all the material is accountable. Inferring drift only from downwind deposition measurements can provide inaccurate information due to sampling errors, the influence of vegetation on the samplers, and the large observed variations in deposition velocities within 200 meters of the source. Without the vertical resolution of air concentrations obtained from the tower samplers (measured during the experiments but not discussed here) a large drift component could go unnoticed if it were elevated above the surface air samplers.
2. The initial drift and drift deposit components varied by only a factor of two or so, depending on the production of smaller droplets, as various techniques were used to put the herbicide down from the aircraft. Meteorological conditions become increasingly important at greater downwind distances from the source since they affect the manner in which these smaller droplets drift downwind, deposit, and evaporate.
3. These experiments suggest that, for purposes of reducing herbicide drift, applications on cool, humid days act to suppress the evaporation of the droplets and allow the material to deposit more quickly, thereby reducing drift.
4. Drift and drift deposit characteristics of the fixed applications using a low volatile butoxyethanol ester (BE) tracer varied according to meteorology, but test applications of low volatile propylene glycol butyl ether ester (PGBE) using various spray nozzle configurations did not vary in the same manner as the test applications. Differences may be attributed to changes in the drop size spectrum between the fixed and test applications, or to variabilities in micrometeorological conditions between releases.

ACKNOWLEDGMENTS

The cooperation of the Agricultural Research Station, U. S. Department of Agriculture, Yakima, Washington, and in particular Mr. Robert Winterfeld, pilot of the spray airplane utilized in this research, is greatly

appreciated. This research was conducted under Contract TDO-730 from the Pacific Northwest Regional Commission.

LITERATURE CITED

- Drummond, A. M.
1973. Pesticide accountancy workshop. AFA Technical Report #13. The Associate Committee on Agricultural and Forrestry Aviation, National Research Council of Canada.
- Frost, K. R.
1973. Pesticide drift from aerial and ground applications. *Agricultural Engineering* 51(8):460-464.
- Kaupke, C. R. and Wesley E. Yates.
1966. Physical properties and drift characteristics of viscosity-modified agricultural sprays. *Transactions of the ASAE* 9(6):797-799.
- Peckenpugh, J. A., L. M. Reisinger and E. Robinson.
1974. Long-distance atmospheric transport of 2,4-D. Presented at the annual meeting of the Pacific Northwest International Section, Air Pollution Control Association, Paper No. 1974-12, Boise, Idaho, November 17.
- Que-Hee, Shane S., Ronald G. Sutherland and Margaret Vetter.
1975. Glc analysis of 2,4-D concentrations in air samples from central Saskatchewan in 1972. *Environmental Science and Technology* 9(1):62-66.
- Slade, David H.
1968. *Meteorology and Atomic Energy 1968*, U. S. Atomic Energy Commission, Office of Information Services, 445 p.
- Ware, G. W., W. P. Cahill, P. D. Gerhardt and J. M. Witt.
1970. Pesticide drift IV: On-target deposits from aerial application of insecticides. *Journal of Economic Entomology* 63(6):1982-1983.
- Yates, Wesley E. and Norman B. Akesson.
1966. Characteristics of drift deposits resulting from pesticide applications with agricultural aircraft. Presented at the 3rd International Agricultural Aviation Congress, Arnheim, Netherlands.
- Yeo, D. and B. W. Thompson
1953. Deposition of a coarse aerosol released from a low-flying aircraft. *Nature* 4369:168-169.

Smoke Dispersal from a Controlled Fire Over a Logged Pine Forest Area^{1,2}

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D. T. Williams, P. W. Ryan, and W. H. McNab^{4/}

Abstract.--The dispersion of smoke in the atmosphere was studied during a controlled fire of forest debris. An instrumented aircraft measured smoke density and other parameters in multiple traverses through the smoke plume. The data permitted contour maps of constant smoke density to be drawn in three dimensions. Centerline smoke density reached a maximum of $0.43 \mu\text{g}/\text{m}^3$. Supporting meteorological data were taken at an array of towers (7 towers, each 62 meters high) near the fire, and at different elevations on a TV tower (400 meters high) located 35 km from the site of the fire. The data will permit the testing of mathematical models for the prediction of the dispersion of pollutants in the atmosphere.

Smoke patterns from a fire were measured with an instrumented aircraft. The objectives of the research were to (1) provide a data base for testing models of smoke dispersion, and (2) improve our understanding and prediction capabilities for dispersion of atmospheric pollutants in general. This paper discusses the experimental data. A later paper will discuss the suitability of models for predicting dispersion.

Site Description

The topography of the control burn area is moderately hilly with an elevation change of about 15 m from the highest to lowest point. The area had been covered with an even-age pine stand which was harvested by clear-cutting a few months before the fire. The soil is

sandy through most of the area, and drainage of moisture proceeds rapidly after rainfall. This promotes rapid drying of forest fuels. There was no measurable rainfall in the three-day period preceding the fire; however, the relative humidity was high. On the day of the fire the minimum humidity was 42%. The high temperature for the day was 22°C . The mass of fuel on the ground before burning was estimated to be 32.5 metric tons per hectare. The fuels consisted of 23.3 metric tons per hectare of logging slash and 9.2 metric tons per hectare of forest floor litter. Post burn measurements indicate that 5.6 tons per hectare of logging slash and 6.1 metric tons per hectare of forest floor litter were consumed during the fire. The area burned by the fire was 15 hectares.

Meteorology and Climatology

Climatology data were available from a weather station maintained on the Savannah River Plant site by the Savannah River Laboratory, and from the U.S. Weather Bureau station at Bush Field in Augusta, Georgia. Mesoscale meteorological information was available for the period of the fire from a network consisting of an instrumented 400-meter TV tower and seven instrumented 62-meter towers. The nearest tower of the seven-tower system is approximately 4 km from the site of the fire. The TV tower is located approximately 35 km from the site of the fire. The instruments are scanned by a computer-controlled data acquisition system and stored on tape. The system can be interrogated at any time and will produce a map with the wind vectors from the seven

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^{3/} Savannah River Laboratory, E. I. du Pont de Nemours and Co., Aiken, South Carolina, and Duke University, Durham, North Carolina, respectively.

^{4/} Southern Forest Fire Laboratory, U.S. Forest Service, Macon, Georgia.

tower system and the temperature profile from the TV tower. The TV tower is instrumented to measure wind speed, horizontal wind direction, vertical wind direction, and temperature at seven levels from 10 to 330 meters. The instrumentation is capable of taking data with sufficient accuracy and time response to monitor the turbulent characteristics of the atmosphere as they relate to dispersion (see Crawford 1974 for more detail). Table 1 shows an example of the data available for a time period during the controlled fire.

Aircraft Data Acquisition

Measurements of smoke dispersal were made by flying transects through the smoke plume with an instrumented aircraft. The aircraft was a Martin-404 flown by EG&G, Inc., of Las Vegas, Nevada. The aircraft instruments recorded the following information:

- Greenwich time
- analog output of an epsilon meter, which provided a measure of atmospheric turbulence
- distance from two base points A and B measured by a microwave range system
- wind speed
- wind direction
- radar altitude
- pressure altitude
- air temperature
- dew point temperature
- air speed
- absolute air pressure
- analog output of nephelometer, which provided a measure of the smoke density

Table 1.--An example of the TV tower and seven tower system output averaged over the period 14:05-14:15 EST

	TV Tower						
	2	10	36	91	137	243	335
Height (m)							
Temperature (°C)	20.7	20.0	a	18.8	18.4	17.5	16.5
σ_T	0.2	0.2	a	0.1	0.1	0.1	0.1
Height (m)	10	36	91	137	182	243	304
Wind speed (m/s)	1.9	2.6	a	a	3.0	2.5	1.9
σ_s	0.6	0.6	a	a	0.7	0.7	1.2
Azimuth (°)	201	198	200	205	205	210	205
σ_a	22.6	13.6	13.0	12.5	13.2	15.5	12.4
Elevation (°)	-1	+5	-6	a	a	-12	a
σ_e	11.4	12.3	12.5	a	a	15.8	a
	Seven Tower System						
	A62	C62	D62	K62	F62	H62 ^b	P62
Location							
Wind speed (m/s)	2.1	2.0	a	a	3.3	2.0	1.2
σ_s	0.5	0.9	a	a	0.8	0.7	1.0
Azimuth (°)	239	171	225	a	238	179	204
σ_a	25.2	14.4	25.6	a	42.0	17.2	49.2
Elevation (°)	52	58	62	120	51	58	67
σ_e	15.8	15.7	10.8	10.0	19.6	12.7	25.8

σ_T = standard deviation of temperature measurements

σ_s = standard deviation of wind speed measurements

σ_a = standard deviation of azimuth measurements

σ_e = standard deviation of elevation measurements

a. data missing or of poor quality.

b. tower nearest fire location.

Measurements were made at one-second intervals and stored on magnetic tape. The aircraft had an average speed of 90 m/sec. The flight pattern of the aircraft was designed to define the plume in three dimensions. Flight passes at 90° to the wind direction were made at altitudes above ground of 160, 400, 500, 725, and 850 meters 1.6 km downwind from the fire. The time of the flights were 14:00, 14:05, 14:09, 14:13, and 14:17, respectively. Passes were made 8 km downwind at the visible base and top of the plume. Passes were also made along the length of the plume, one pass above the visible centerline and one pass along each edge of the plume.

The aircraft was equipped with a multi-spectral photographic system which included an infrared scanner. Photographs and infrared scans were taken over the fire to determine visible plume width and an estimate of the area of fire.

Infrared Scans and Color Photography

Data from the aerial infrared scans (Figure 1) showed the progress of the fire. The fire was started at 13:15 EST December 5 as a backfire and then the entire area was fired from the edge. The infrared scans indicate that the north end of the fire burned first, and was noticeably cooler by the time the rest of the area was burning. Similar patterns could be seen from color photographs at the initial stages of the fire but were later obscured by smoke. The area had completely burned over by 16:30 EST but continued to smolder through that night.

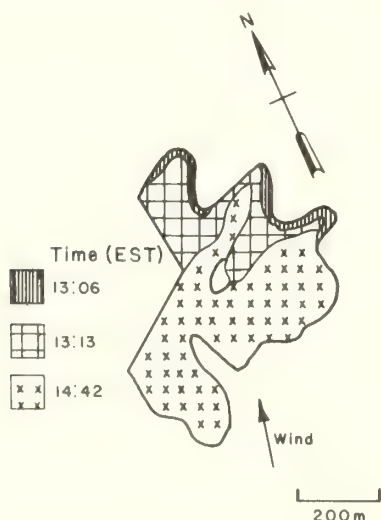


Figure 1.--Map of the burned area showing how the fire progressed. Data were obtained with an infrared scanner at the times indicated.

Climatological and Meteorological Observations

The wind speed aloft averaged 2.5 m/sec at an azimuth of 180-240°. The entire period was characterized by surprisingly persistent wind. Table 2 shows selected values of the standard deviations of the wind azimuth angle and elevation angle during the period of the controlled fire. The temperature profile of the TV tower and the standard deviation of the wind azimuth and elevation angle indicate unstable atmospheric conditions which favor dispersion of the plume.

Table 2.--Selected values of meteorological parameters from the 62 meter tower nearest the fire

Time	σ_e	σ_a	Azimuth, degrees	Wind Speed, m/s
14:00	14.8	21.5	239	2.0
14:15	12.7	17.2	179	2.0
14:30	12.9	14.4	201	2.0
14:45	17.1	34.2	182	1.2
15:00	10.8	23.5	227	1.7
15:15	9.9	16.3	218	2.2

Flight Data

The first step of data analysis was to scale the input parameters in meaningful units. Most of the parameters were prescaled by the data acquisition system and required only changes to consistent metric units. The nephelometer output was scaled by the equation

$$\chi = 38 S (V - B) \quad (1)$$

where

χ = mass per volume of air ($\mu\text{g}/\text{m}^3$)

S = one of three scale factors for the nephelometer

V = instrument voltage (0-5 v)

B = background signal (0.08 v).

Figure 2 shows the output of the epsilon meter, the air temperature, the pressure altitude, and the nephelometer. The effect of the presence of the plume is seen in the increase in turbulence registered by the epsilon meter, the increase in air temperature, and the increase in the density of smoke as measured by the nephelometer. The displacements in the peaks of the turbulence, temperature, and density of smoke are most likely to have been caused by the different response times of the instruments.

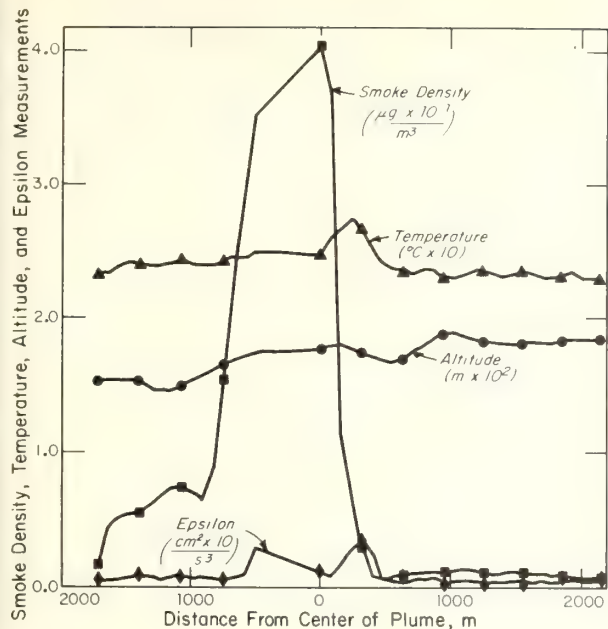


Figure 2.--Smoke plume data at an altitude of 160 meters for a flight path perpendicular to the wind direction.

Figure 3 illustrates the density of smoke in the plume at five altitudes at a distance 1.6 km from the fire. The general shape of the cross section of the smoke plume is outlined by the contours of constant smoke density. At a distance of 1.6 km, the plume is denser and wider at the highest flight path. U.S. Weather Bureau soundings from Charleston, S.C., and Athens, Ga., indicated the height of the mixing layer was about 1000 m at 1900 EST on the day of the fire. Thus, it seems that under the low wind speed condition which prevailed during the fire, the majority of the buoyant plume quickly rose to the top of the mixing layer and diffused in an approximately Gaussian manner in the horizontal plane. However, the vertical smoke density profile does not seem to be a simple Gaussian model with diffusion from an apparent elevated source. The high centerline concentrations at the lower altitudes can be interpreted as leakage from the buoyant smoke column produced by the fire, or as multiple sources from the actively burning and burned-over, smoldering portions of the fire. In either case, it is clear that the character of smoke dispersion from a forest fire will vary with the stage of the fire's development, from a fairly hot fire that has just been set, through the stage of maximum combustion, to the stage of smoldering remnants.

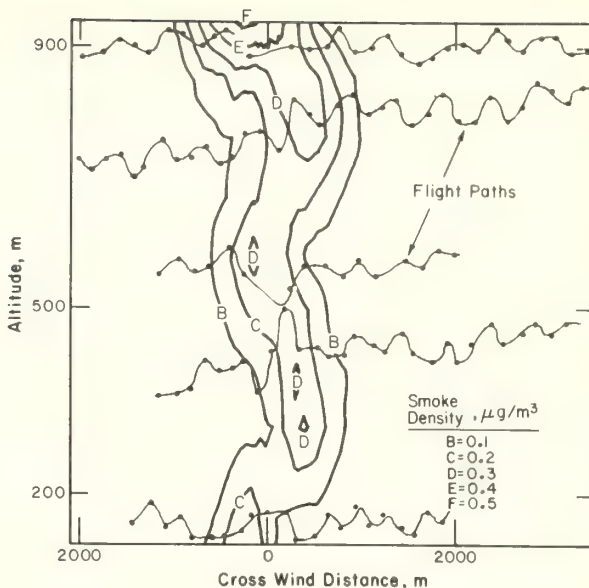


Figure 3.--Smoke plume density above the fire.

Mathematical models for describing the smoke plume behavior during the fire are currently under development.

Reference

- Crawford, T. V.
1974. Progress Report, Dose-to-Man Program FY 1973, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S.C. DP-1341, 91 pp.

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Synoptic Scale Haziness over the Eastern U.S. and Its Long Range Transport¹

N. V. Gillani and R. B. Husar^{2/}

Abstract -- The development and long range transport of synoptic scale haziness affecting much of the eastern U.S. is studied using daily visibility contours, air parcel trajectories and air quality data. It is shown that sulfates and ozone are major ingredients of the associated air pollution over large exposed areas.

1. INTRODUCTION

In-situ generation of secondary ozone and visibility-reducing aerosols during transport of the urban plume of St. Louis has been demonstrated to cause a significant deterioration of ambient air quality over a downwind range well in excess of the mesoscale (White, et al., 1976). The pollutant plume from a large coal-fired power plant near St. Louis has also been tracked downwind for nearly 300 km. (unpublished data of Project MISTT, 1976). These observations represent direct evidence of the long range transport of atmospheric pollution. Long range transport processes, acting simultaneously on effluents from a large number of sources, are believed to be largely responsible for the observed high levels of rural ozone (Ripperton, et al., 1975) and sulfates (EPA, 1975) over wide regions of the eastern U.S. The role of long range transport in regional air pollution phenomena is perhaps most vividly illustrated by the export of synoptic scale hazy air masses from a given source region to distant and wide

areas of exposed receptor regions. Such synoptic scale polluted air masses ('blobs')³ can develop over a region with substantial emissions from a large number of sources when meteorologically stagnant conditions (low wind speeds and/or mixing depths) persist over the region for several days. In this paper, we present the case study of a synoptic scale air pollution episode which resulted when a 'blob' formed in the industrialized northeastern region of the U.S. and continued its residence over various parts of the eastern half of the country for a period of nearly two weeks during the summer of 1975. In the exposed areas, the passage of the 'blob' was characterized by very low visibilities, high ozone levels and, based on limited available aerosol data, also high concentrations of fine particulates including sulfates. The existence of haziness on the scale of an entire synoptic air mass has recently been observed based on visibility reduction and suspended particulate data (Hall, et al., 1973), as well as on visual data from satellite studies (Lyons, 1975).

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^{3/} Random House Dictionary (1966):

'blob' - an object, esp. a large one having no distinct shape or definition;

here, 'blob' - "large hazy air mass".

2. DATA BASE FOR THE ANALYSIS

Studies aimed at the investigation of spatial-temporal scales and pollutant variability of regional scale air pollution continue to be hampered by the lack of large-scale air quality network data. The National Air Surveillance Network (NASN) data for sulfates, for example, were available to us from about 60 stations in the eastern half of the U.S. These data consist of 24-hour sulfate concentrations based on hi-volume filter samples collected only once every 12 days. EPA's SAROAD data base was used for ozone concentrations (hourly average), recorded regularly at 89 local aerometric monitoring stations in the eastern U.S. An attractive qualitative surrogate for visibility-reducing aerosol data in studying the spatial extent and temporal behavior of large hazy air masses in the U.S. is the surface visual range observations made every hour at more than 300 airport stations of the National Weather Service (NWS) network (Service A). The high spatial density of this network permits the meaningful use of computer contour plotting techniques. Using the visibility data, the spatial extent, the temporal evolution and the transport of hazy 'blobs' may be followed for several days by inspection of chronological visibility contour maps. Daily weather maps prepared by the NWS and surface wind

patterns, as well as long-range air parcel trajectories constructed from upper air network data (USAF-ETAC) are also used. Finally, detailed local air pollution data of aerosol mass, and sulfate and ozone concentrations are used whenever possible to check for consistency of the synoptic pollution patterns with such local measurements.

3. RESULTS

Visibility and Weather Maps:

Successive contour maps of noon visibility (Fig. 1) were plotted for each day from June 25 through July 5, 1975 (every second day shown). Noon visibilities were chosen to minimize the effect of the early morning ground fog on the visibility contours. For inland stations, the noon relative humidity commonly ranged between 50% and 80%. The visibilities used have not been corrected for relative humidity effects. The different shaded regions in the figure correspond to different observed visual ranges $V(m)$, or equivalently, to different levels of light extinction coefficient $b_{ext}(m^{-1})$. The two quantities are related by (Middleton, 1952):

$$b_{ext} = \frac{3.912}{V}$$

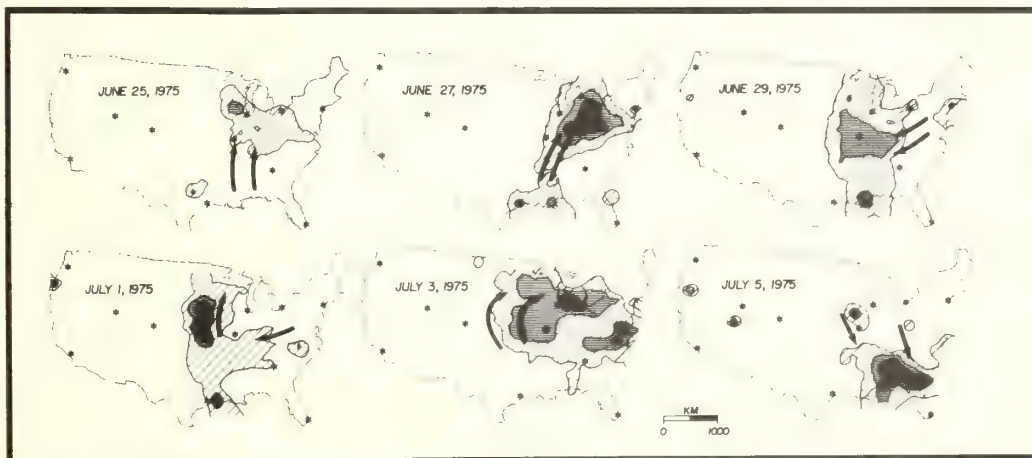


Figure 1. Sequential contour plots of noon visibility at ground level for the period June 25 to July 5, 1975. Contours are for $b_{ext} = 4, 6, 8 (10^{-4} m^{-1})$, corresponding to approximate visual ranges of 4-6 miles (light shade), 3-4 miles (medium shade), and <3 miles (black).

Inspection of the sequence of maps reveals that multi-state regions are covered with a haze layer in which the noon visibility is less than 6 miles ($b_{ext} > 4 \times 10^{-4} \text{ m}^{-1}$).

The day-to-day motion of these hazy 'blobs', as revealed by direct inspection of the sequential plots, is checked for consistency by comparison with the long-range motion of corresponding air parcels. The long-range air parcel trajectories are computed using a computerized *post-facto* trajectory model (Heffter and Taylor, 1975) intended primarily for use in calculating pollutant transport on a regional scale. The calculated trajectories used here are at 6-hour intervals, backward for 3 days from any given destination, and use observed and interpolated winds averaged between 250 and 1000 m above average terrain. From long-range air parcel trajectory calculations and surface wind information, it was determined that the air mass of June 25, within which the visibility was less than 6 miles, was of maritime origin in the Gulf of Mexico (see Fig. 3A). This air mass had been transported in a northerly flow across Louisiana, Arkansas, Illinois and Indiana. Between June 25 and 27, a NNE trajectory prevailed in the southern states, but relative stagnation prevailed in the

southern Great Lakes and Ohio River valley region. In this region of stagnation, the air mass became increasingly hazy, presumably as a result of accumulating pollution from the high pollutant emission-density of this region of the U.S.

The daily weather maps for the period June 29 through July 4, 1975 are shown in Fig. 2. A major feature of the weather system during that period was the tropical storm "Amy", moving up off the northeast coast. By its presence, the tropical storm provided a barrier against large scale eastward motion. From the northwest, a front was approaching the Great Lakes. Between June 28 and 30, as the storm advanced north, an easterly flow developed inland, causing the hazy air mass to drift slowly westward, passing over St. Louis, MO on June 28-29 (see Fig. 3B) and continuing across Missouri and Kansas (June 30). Midday visibilities over eastern Missouri deteriorated to less than 3 miles at the peak of the episode. Weather satellite pictures of the area on June 30 revealed the presence of the hazy air mass in the same region as that obtained by visibility contour plotting (Lyons and Husar, 1976). From June 30 to July 2, the hazy air mass moved in the clockwise circulating wind pattern (associated with the high pressure

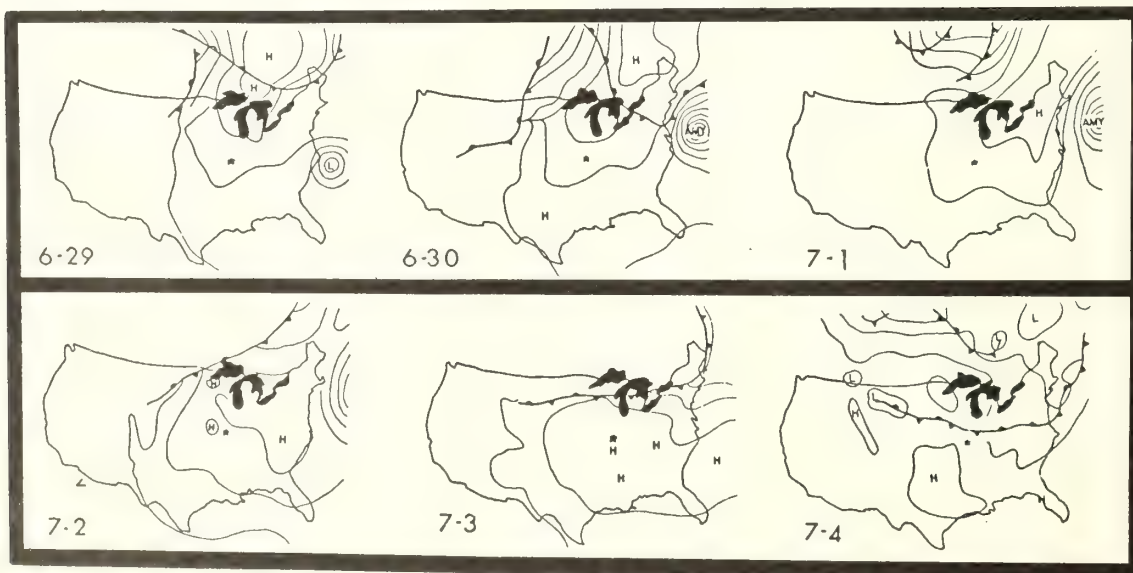
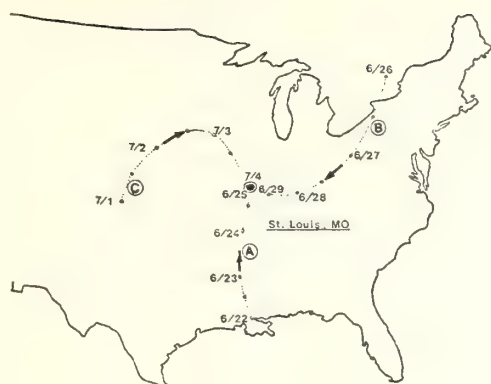


Figure 2. Daily U.S. weather maps, June 29 - July 4, 1975.



DESTINATION	ARRIVAL
(A) : St. Louis, MO	12 Z, 6/25/75
(B) : "	" 6/29/75
(C) : "	" 7/04/75

Figure 3. Three-day backward air trajectories arriving in St. Louis.

region below the front) up and around to the southern Great Lakes region (see Fig. 4A,B). In the meantime, pollutant emissions continued into this high pressure region. By July 3, the Canadian front had itself reached the southern Great Lakes, and it formed the northern border of a massive hazy blob occupying most of midwestern and northeastern U.S. Once again, the visibility deteriorated to less than 3 miles near St. Louis, MO. In the next two days, the cold front rapidly advanced southward, passing over St. Louis on July 4 and continuing on. As the front advanced, the hazy blob was pushed ahead of it (see Figs. 3C and 4C). By July 5, the blob was in southeastern U.S., and the visibility was less than 4 miles over Atlanta, GA, Birmingham, AL, and Tallahassee, FL.

Sulfate and Ozone Maps:

There exists a strong correlation between aerosol mass concentration in the size range of 0.1 to 1 μm diameter and the extinction of light by scattering (Charlson, 1969; Hidy et al., 1974). Furthermore, measurements in and near St. Louis, MO have shown that sulfates often account for 50% or more of the aerosol mass in this size range (Charlson et al., 1974). The significance of the use of visibility data as a surrogate for atmospheric pollution



DESTINATION	ARRIVAL
(A) : Minneapolis, MINN	12 Z, 7/01/75
(B) : Columbus, OH	00 Z, 7/03/75
(C) : Atlanta, GA	18 Z, 7/04/75

Figure 4. Three-day backward air trajectories arriving at destinations shown.

may thus be checked by direct comparison of the visibility maps with corresponding maps for sulfate. NASN sulfate data were available for June 23 and July 5, 1975. These are shown plotted in Fig. 5 in the form of contours over the eastern half of the U.S. The contours are hand-plotted because the density of data points was judged too sparse to justify computer plots. Direct comparison of visibility and sulfate maps for the two days clearly shows a substantial positive correlation between the two. Sulfate concentrations in excess of 30 $\mu\text{g}/\text{m}^3$ are seen to coincide with regions of lowest visibility.

During the period considered in the present case study, insolation was generally above seasonal norms. Under similar conditions, high rural ozone levels have been observed in conjunction with high concentrations of light scattering aerosols (White et al., 1976). In order to examine the correlation between ozone and visibility reduction on a synoptic scale, contour plots were also prepared (by hand) for ozone for the period June 25 through July 3, 1975 (Fig. 6). Ozone values shown are daily maximum levels which are attained in the early afternoon. The plots show that the U.S. standard concentration for ozone (0.08 ppm) was exceeded over large areas of the eastern U.S. on all days of the air pollution episode.

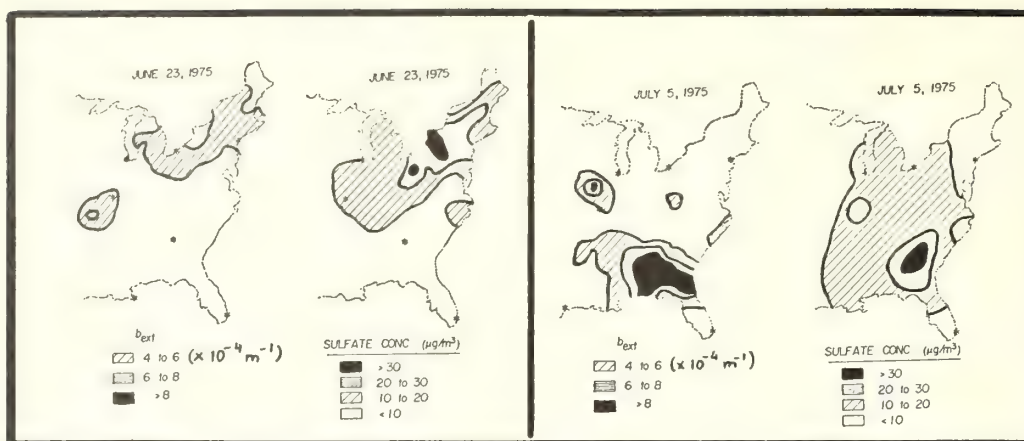


Figure 5. Comparison of contour plots of noon visibility reduction (b_{ext}) and 24-hour sulfate concentration for 6/23 and 7/5/1975.

Comparison of the maps for visibility and ozone (Figs. 1 and 6 respectively) reveals that the geographical location of high ozone concentrations roughly corresponds to the areas of low visibility (and high sulfate). As may be anticipated, however, the correlation with haziness (low visibility) is much better for sulfates than for ozone.

Local Air Pollution Data (St. Louis, MO):

Data for ozone and light extinction coefficient for St. Louis, MO are shown in Fig. 7 for the entire summer of 1975. The surface ozone data exhibit the typical diurnal pattern consisting of near-zero readings during the night and early morning, and peaks in the early afternoon followed by a drop during the evening hours. The two passages of the hazy

blob over St. Louis are confirmed by the elevated peaks for both ozone and b_{ext} during the periods June 27-29 and July 2-4.

The two episodes of air pollution in St. Louis during the period of the case study are also evidenced by the data of light scattering coefficient (b_{scat}) measured locally using integrating nephelometers (Fig. 8a). The data were collected at three widely-spaced local air monitoring stations. One of the stations is situated in the city (station 4), one on the outskirts of the city (station 9), and one at a background location (station 6) about 40 km to the west of the city. The data from all three stations reveal a common temporal pattern of atmospheric fine particulate loading, thus confirming that

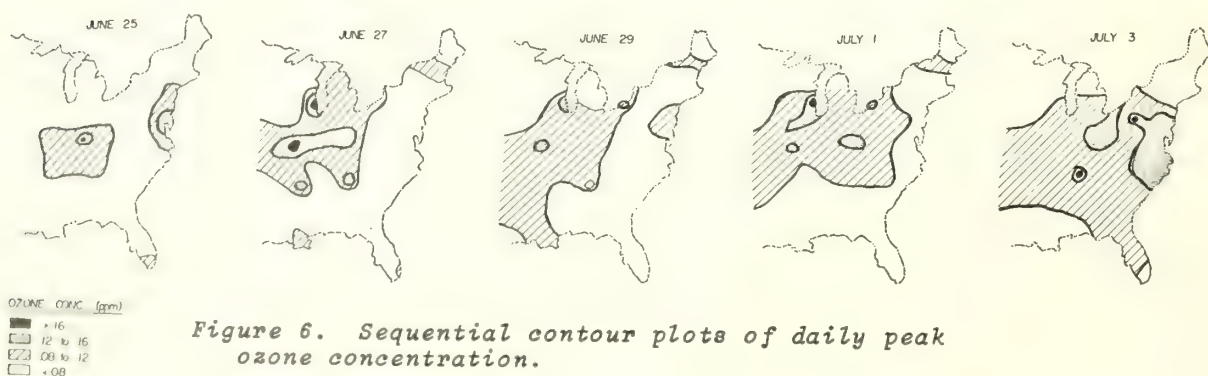


Figure 6. Sequential contour plots of daily peak ozone concentration.

the major changes in the light scattering coefficients during the entire period occurred over a spatial scale substantially greater than that of the St. Louis metropolitan area. These data also indicate that the increase in the light scattering aerosol concentrations during this period were the result of external inflow rather than of local source contributions. Fig. 8b shows the temporal variations of the light extinction coefficient computed based on observed visibility ranges at the major airports of St. Louis, MO and Springfield, IL. The two observation sites are about 150 km apart. Both traces reveal the two passages of the blob whose spatial scale is larger than the separation of the sites. The time offset of the two traces is much smaller than the temporal scale of each blob passage over the region, and is due to the separation of the sites. Comparison of Figs. 8a and b reveals a close correlation between the actual measured light scattering coefficient (b_{scat}) and the light extinction coefficient (b_{ext}) inferred from visibility data. This correlation demonstrates the utility of visibility observations as a qualitative surrogate for aerosol concentration of the atmosphere.

The daily average sulfate concentrations using Hi-Volume filters were measured before, during, and after the passage of the hazy air mass over St. Louis, MO. Hi-Volume filter samples, collected every six days by the St. Louis County Department of Health, were analyzed for particulate sulfur using flash volatilization-flame photometric detection method (Husar et al., 1975). An increase from $9.2 \mu\text{gm}^{-3}$ on June 23 to $32.7 \mu\text{gm}^{-3}$ on June 29 is shown in Fig. 8a. The sulfate content then dropped to $8.0 \mu\text{gm}^{-3}$ on July 5 after the passage of the Canadian front. Sulfate accounted for 19% of total aerosol mass before, 34% during, and 15% after the passage of the hazy air mass. The daily average sulfate concentrations were compared to daily average b_{ext} (uncorrected for relative humidity effects) for the entire summer (June, July, August 1975). The correlation coefficient was found to be $r = 0.7$ and the regression equation for sixteen points was $b_{\text{ext}} [10^{-4} \text{m}^{-1}] = 3.24 +$

$$0.11 \text{SO}_4^{--} [\mu\text{gm}^{-3}].$$

These results tend to suggest that a substantial fraction of the haze aerosol, particularly during the passage of 'blobs', was associated with sulfates.

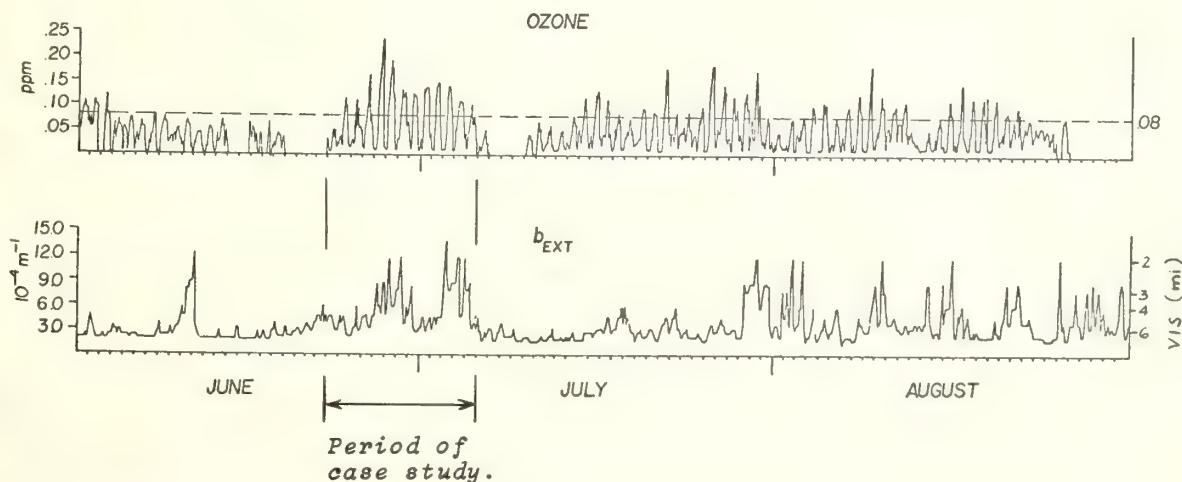


Figure 7. Comparison of long-term observations of ozone light extinction coefficient at an air monitoring station in St. Louis, MO.

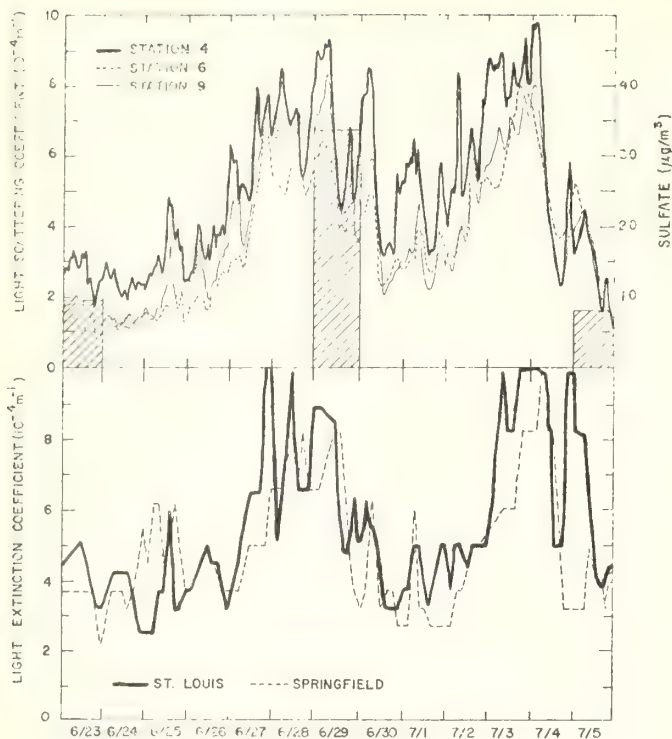


Figure 8. a) Light scattering coefficient, b_{scat} , recorded by nephelometers at three stations of the St. Louis City/County air monitoring network. Similar b_{scat} records (not shown here) were also recorded at the other stations in the network; b) Light extinction coefficients, b_{ext} , determined from visibility observations at St. Louis Lambert Airport and Springfield, IL Airport (150 km apart).

Effect of Relative Humidity:

As stated earlier, no corrections have been made to the visibility data for the contribution of relative humidity. However, the plots correspond to visibility observations at noon when the reduction of visibility due to fog or "water haze" is minimal. To investigate the effects of geographical location as well as relative humidity on local visibility observations, all hourly data for visibility and relative humidity for the entire period of June, July and August of 1975 were plotted for four widely-spaced stations, as shown in Fig. 9. For all four stations, the change in b_{ext} is small for

increasing R.H. up to about 75%. For higher values of R.H., there is a sharp reduction of visibility. Thus, visibility reduction is mostly due to pollution for R.H. less than 75%, and substantially due to water vapor for R.H. above 75%. Also, average summer visibility due to pollution (R.H. < 75%) is much lower at Huntington, W.VA than at San Antonio, TX. The distribution of haziness over the entire U.S., seasonally averaged for the summer months, and considering only those local observations which correspond to R.H. in the range of 60-70%, is shown in Fig. 10. The lowest visibilities are observed to be in the north-eastern section of the U.S., with the worst conditions prevailing in the region of the Ohio River valley. This is also roughly the region of highest emission density of SO_2 in the U.S., indicating the possible dominance of aerosols of anthropogenic origin in causing visibility reduction at R.H. below about 70%.

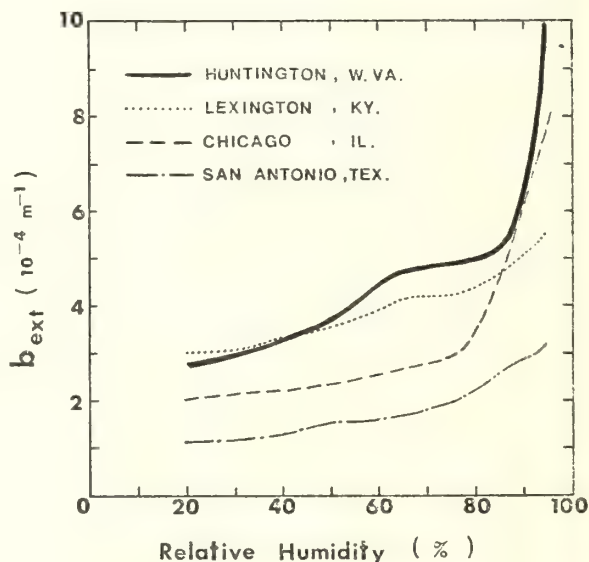


Figure 9. Light extinction coefficient in four U.S. cities for different ranges of relative humidity during Summer 1975. b_{ext} is determined by averaging all observations (for entire summer) which are in given RH ranges (e.g. 20-30%, 30-40%, and so on).

JUNE, JULY, AUGUST, 1975

REL. HUMIDITY 60-70 %

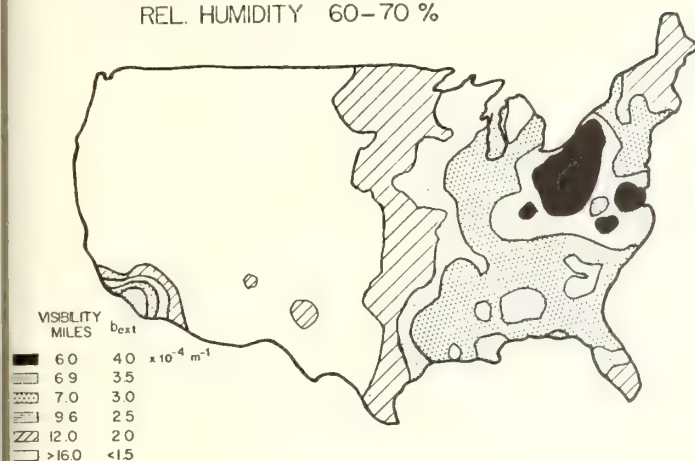


Figure 10. Geographical variation of b_{ext} for RH = 60-70% during summer 1975.

CONCLUSION

This brief analysis of national visibility data, synoptic weather maps, air parcel trajectories and national as well as local air quality data, points out two intriguing phenomena. Multi-state scale haziness may be caused by the accumulation in the atmosphere of pollutant emissions from one region and its subsequent transport over a long range. Secondly, a major fraction of the pollutant content of such large hazy air masses is constituted of secondary ozone and aerosols, mainly sulfates. Evidently, the role of meteorology is important in the occurrence of such regional scale pollution episodes lasting many days, even weeks. A much more intriguing question may be raised concerning the possibility of synergism between the ozone and sulfate contents of such polluted air masses. What is the role of such interactions in the origin and spread of such large scale air pollution episodes?

ACKNOWLEDGMENT

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REFERENCES

- Charlson, R.J., 1969: Atmospheric visibility related to aerosol mass concentration. *Environ. Sci. Technol.*, 3 (10), 913-918 (October).
- Charlson, R.J., 1974: Sulfuric Acid and Ammonium Sulfate Aerosols: Optical Detection in the St. Louis Region. *Science*, 184, 156.
- Hall, F.P. et al., 1973: Long-range transport of air pollution: A case study, August 1970. *Monthly Weather Rev.*, 101 (5), 404-411.
- Heffter, J.L. and Ferber, G.J., 1975: A regional-continental scale transport, diffusion, and deposition model. Part I. Trajectory Model. NOAA TM ERL ARL-50, June 1975.
- Hidy, G.M. et al., 1974: Characterization of aerosols in California, Final Report IV, California Air Resources Board.
- Husar, J.D. et al., 1975: Determination of submicrogram amounts of atmospheric particulate sulfur. *Anal. Chem.* 47, 2062.
- Lyons, W.A., 1975: Satellite detection of air pollutants, in *Remote Sensing Energy-Related Studies*, John Wiley & Sons, N.Y., 263-290.
- Lyons, W.A. and R.B. Husar. SMS/GOES visible images detect synoptic scale air pollution episode, (to be published).
- Middleton, W.E.K., 1952: *Vision through the atmosphere*. pp. 60-82, Univ. of Toronto Press, Toronto.
- Ripperton, L.A. et al., 1975: Urban photochemistry and rural transport. Paper presented at APCA Meeting, Mid-Atlantic States Section, Newark, N.J., Oct. 1975.
- White, W.H., et al., Formation and transport of secondary air pollutants: ozone and aerosols in the St. Louis urban plume. *Science*, 194, p. 187, Oct. 1976.
- EPA, 1975: Position paper on regulation of atmospheric sulfates. EPA-450/2-75-007, September 1975.

Baker, Douglas H., and Michael A. Fosberg. [tech. coord.] 1976. Proceedings of the fourth national conference on fire and forest meteorology, St. Louis, Missouri, Nov. 16-18, 1976. USDA For. Serv. Gen. Tech. Rep. RM-32, 239 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

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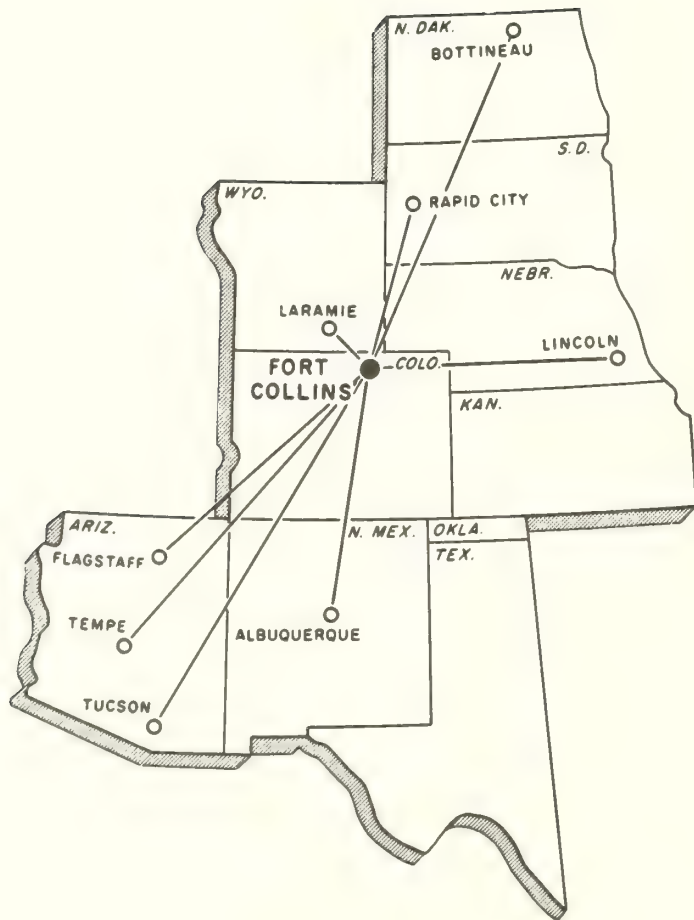
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Shade Materials for Modifying Greenhouse Climate

USDA Forest Service
General Technical Report RM-33
Rocky Mountain Forest and
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Forest Service
U.S. Department of Agriculture
Fort Collins, Colorado 80521

December 1976



Abstract

Davis, Edwin A., and Frank D. Cole.

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Shade Materials for Modifying Greenhouse Climate

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Shade Materials for Modifying Greenhouse Climate

Edwin A. Davis and Frank D. Cole

Background

Alternatives for shading research greenhouses are limited for modifying temperature and light intensity. Two important characteristics of shading materials for a research greenhouse are that they allow alteration of shading patterns and degree of shading, and provide for ease of installation and removal. Temperature regulation is an important function of shading, especially for greenhouses in areas where evaporative cooling is not completely effective.

Several types of shade materials are used for greenhouses. Whitewash paint (Ekblad 1973) is economical and easy to apply, and with careful application, multiple coats may be used to provide a range of light intensities. However, uneven application or large variations in greenhouse light intensity caused by the collection of dirt or loss of paint by rain may be detrimental if any degree of precision in light intensity is required. Also, light intensity cannot be conveniently modified once paint is applied.

A flowing layer of water has been used with some success; some attempts have been made to absorb more of the infrared radiation by adding various compounds to the flowing water (Canham 1964). An advantage of this system is that it could be automated. Initial cost, a requirement for relatively soft water and a filter system, corrosion to metal glazing bars, and the difficulty of preventing leaks were cited as disadvantages.

Wooden lath, another traditional shading material, is difficult to install, initial cost is high, and its appreciable weight may be undesirable on a greenhouse roof (Canham 1964).

Objectives of this study were to determine effects of several types and locations of shading materials on greenhouse temperatures, and on light intensity, distribution, and quality.

Materials and Methods

All studies were conducted in three glass greenhouses, 15 feet wide by 41 feet long, in Tempe, Arizona. Greenhouses were oriented north and south, were parallel, and were 8.5 feet apart.

Shade materials chosen for comparison included Alsynite corrugated fiberglass panels in luminous white, and synthetic fiber shade cloths (fig. 1). The fiberglass panels, installed inside the greenhouse between the rafters, resulted in a light transmission value of approximately 30 percent, or a shade rating of 70 percent. The shade cloths used were Lumite

Saran, a green fabric with a rating of 80 percent shade, and Prop-a-lite polypropylene, black fabrics with ratings of 80 and 55 percent shade. Average life for Saran is 6 to 7 years, with a shrinkage factor of 3 to 4 percent. Average life of Prop-a-lite is 10 to 15 years, with a shrinkage factor of less than 1 percent.

The shade cloths were installed either inside the greenhouse on specially installed hangers, or outside, draped over the top and sides of the greenhouse and secured with weights fastened to grommets in the shade cloth.

Temperatures were measured with shielded maximum-minimum mercury thermometers at bench height at the same location in each greenhouse. Thermometers were calibrated against a standard mercury thermometer, and were rotated daily among greenhouses to minimize discrepancies.

Light intensities were measured with a Weston Illumination Meter (Model 756) with its photocell perpendicular to the sun. Solar radiation was measured by a Yellott, Mark IV Sol-A-Meter or a Kipp and Zonen Solarimeter. An ISCO Model SR Spectroradiometer was used to measure light quality.

All data were subjected to analyses of variance and means were tested for significance according to Duncan's New Multiple Range Test.

Results

Effects of Shade Materials on Greenhouse Temperatures

Effects of three types of shading on greenhouse temperatures during winter, spring, and summer are shown in table 1.

Winter.—The average maximum outside temperature during the winter test period, January 12 to March 7, was 62.0°F. Shade comparisons made during the winter months were between no shade, fiberglass panels inside, and Saran 80 percent shade cloth inside. Evaporative coolers were off, and heaters were on at night. The average maximum greenhouse temperature with Saran 80 percent shade cloth inside was 100.6°F, 11.1°F warmer than with fiberglass panels inside, and 7.2°F warmer than the unshaded greenhouse.

With heaters on at night, the average minimum temperatures with fiberglass panels or shade cloth inside were essentially the same; both raised greenhouse night temperatures about 6.6°F above that in the unshaded house.



Figure 1.—Types of shading evaluated:

Fiberglass panels installed inside the greenhouse between the rafters.



Saran 80 percent shade cloth installed inside.



Prop-a-lite 55 percent shade cloth installed outside.

Table 1.--Average greenhouse temperatures (°F, bench height) without shading, with fiberglass panels inside, and with Saran 80 percent shade cloth inside or outside (means in rows not followed by same letter are significantly different at the 5 percent level)

Time of year and temperatures	Sample size	No shade	Shade material and location			Outside air
			Fiberglass panels, inside	Saran 80 percent shade cloth		
				Inside	Outside	
WINTER (JAN. 12 - MAR. 7)	55					
Coolers off; heaters on at night and off during day; top vents closed at night and open or closed during day, depending on weather						
Maximum temperature		93.4b	89.5a	100.6c		62.0
Minimum temperature		56.0a	62.8b	62.5b		34.7
Difference between inside and outside mean maximum		+31.4	+27.5	+38.6		
SPRING (MAR. 23 - 29)	7					
Coolers and heaters off; top vents open night and day						
Maximum temperature			95.7a	109.7b	88.4a	74.4
Minimum temperature			58.7a	57.3a	57.7a	49.7
Difference between inside and outside mean maximum			+21.3	+35.3	+14.0	
SUMMER (MAY 21 - JULY 25)	66					
Coolers on, with water; heaters off; top vents open night and day						
Maximum temperature			92.8b	94.4c	88.1a	103.9
Minimum temperature			72.1b	69.6a	69.3a	68.4
Difference between inside and outside mean maximum			-11.1	-9.5	-15.8	

Spring.—The average outside maximum daytime temperature for the spring test period, March 23-29, was 74.4°F. Both coolers and heaters were off and top vents were open continuously. Under these conditions, 80 percent shade cloth outside gave an average maximum greenhouse temperature of 88.4°F, 21.3°F cooler than with shade cloth inside, and 7.3°F cooler than with fiberglass panels inside; the latter difference, however, was not significant at the 5 percent level.

Spring greenhouse temperatures at night with heaters off were approximately equal regardless of shading material or its location.

Summer.—During the summer test period, May 21 to July 25, the average maximum outside temperature was 103.9°F. With evaporative coolers on, 80-percent shade cloth outside resulted in the lowest average maximum greenhouse temperature (88.1°F). The average maximum greenhouse temperature with fiberglass panels inside was 92.8°F; with 80 percent shade cloth inside it was 94.4°F.

Minimum greenhouse temperatures with shade cloth inside or outside were essentially equal. Aver-

age minimum greenhouse temperatures with fiberglass panels inside were 2.8°F warmer than those with 80 percent shade cloth outside.

Comparison of 55 and 80 Percent Shade Cloths

Two densities of Prop-a-lite polypropylene shade cloth draped over the greenhouses were compared with "no shade" for their effects on greenhouse temperatures during winter and late spring (table 2).

Winter.—During the winter test period, January 21 to February 28, the average maximum outside temperature was 68.0°F. Greenhouse heaters and coolers were off; top vents were closed at night and open during the day. Average high temperatures under 80 percent and 55 percent shade cloths and "no shade" were 3.7, 9.8, and 22.1°F warmer than the average maximum outside temperature. Minimum greenhouse temperatures under the two densities of shade cloth were not significantly different.

Table 2.--Average greenhouse temperatures ($^{\circ}\text{F}$, bench height) with no shading and with 55 or 80 percent Prop-a-lite shade cloth installed outside (means in rows not followed by same letter are significantly different at the 5 percent level)

Time of year and temperatures	Sample size	No shade	Shade material and location		Outside air
			55 percent shade cloth	80 percent shade cloth	
WINTER (JAN. 21 - FEB. 28) Coolers and heaters off; top vents closed at night and open during day. Not all days in time interval were included.	22				
Maximum temperature		90.1c	77.8b	71.7a	68.0
Minimum temperature		47.1a	45.7a	46.2a	39.1
Difference between inside and outside mean maximum		+22.1	+9.8	+3.7	
LATE SPRING (JUNE 1 - 25) Coolers on, with water; heaters off; top vents open night and day	25				
Maximum temperature			88.6b	82.2a	101.2
Minimum temperature			66.7a	67.2a	62.4
Difference between inside and outside mean maximum			-12.6	-19.0	

Spring.—The average maximum outside temperature during the late-spring period, June 1 to 25, was 101.2°F . The greenhouse evaporative coolers were on, heaters were off, and top vents were open continuously. The average maximum greenhouse temperature under 80 percent shade cloth (82.2°F) was 6.4°F cooler than that under 55 percent shade cloth. Minimum greenhouse temperatures were not significantly different under the two types of shade cloth.

Light Distribution

Foot-candles (fc) of illumination under fiberglass decreased 35 percent from panel to bench, while illumination under an 80 percent shade cloth remained constant (table 3).

Energy intensity (ly min^{-1}) under fiberglass panels decreased 27 percent from 1 foot beneath the greenhouse ridge to the bench; the decrease was only 12 percent under 80 percent shade cloth, however. The slight decrease in energy intensity under shade cloth measured with the solarimeter but not with the illumination meter may be because the solarimeter was positioned horizontally, whereas the light meter was held perpendicular to the sun's rays.

Spectral Distribution

Spectral distribution curves were measured with and without shading material (fig. 2). It appears that the quality of light produced by fiberglass or Saran shade cloth in the visible portion of the spectrum is adequate for plant growth. No important differences can be seen in comparison with sunlight.

Discussion

An advantage in the use of fiberglass panels is that light is diffused and shadows are eliminated. Disadvantages include darkening with age with some types of fiberglass, including the type used in these tests, and higher greenhouse temperatures than those produced under shade cloth installed outside. Although fiberglass is available in different transmittancies and colors, the panels are not as easy to install, remove, and store as shade cloth. Light intensities under fiberglass varied from roof to bench.

Shade cloth placed outside resulted in the most effective control of greenhouse temperature. Other desirable characteristics are convenience of installation and removal, and the availability of a wide

Table 3.--Effect of fiberglass panels and Saran 80 percent shade cloth on light distribution from greenhouse roof to bench

Distance from roof (ft)	Fiberglass panels				Saran 80 percent shade cloth			
	Illumination ¹		Energy intensity ²		Illumination ¹		Energy intensity ²	
	fc	decreases	ly min ⁻¹	decreases	fc	decreases	ly min ⁻¹	decreases
0	4,600	0	--	--	2,200	0	--	--
1	4,000	13.0	0.312	0	2,200	0	0.164	0
2	3,600	21.7	.280	10.3	2,200	0	.155	5.5
3	3,400	26.1	.264	15.4	2,200	0	.153	6.7
4	3,200	30.4	.258	17.3	2,200	0	.153	6.7
5	3,000	34.8	.248	20.5	2,200	0	.149	9.1
6	3,000	34.8	.238	23.7	2,200	0	.145	11.6
7	--	--	.228	26.9	--	--	.144	12.2

¹The photocell of the light meter was held perpendicular to the sun.

²Wavelength of the solarimeter was limited by the glass dome to 280-2,500 nm. Measurements were made vertically beneath a top vent when the sun was nearly overhead. The solarimeter was leveled at each height.

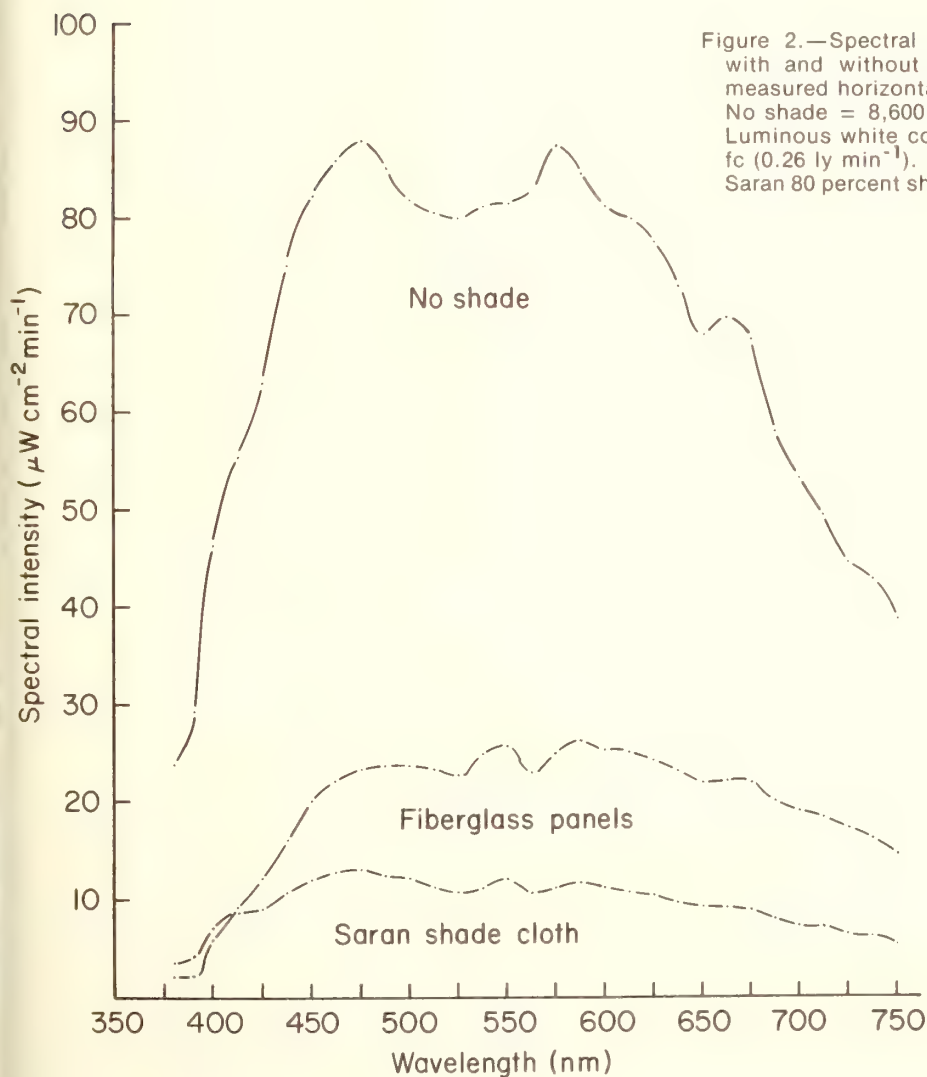


Figure 2.—Spectral distribution curves in greenhouse with and without shade materials. Light intensities measured horizontally were:
No shade = 8,600 fc (0.91 ly min⁻¹).
Luminous white corrugated fiberglass panels = 2,300 fc (0.26 ly min⁻¹).
Saran 80 percent shade cloth = 1,400 fc (0.13 ly min⁻¹).

choice of densities. Light intensities under shade cloth were more uniform from roof to bench than those under fiberglass.

A minor disadvantage of shade cloth installed outside is dirt collection, although it can easily be cleaned by hosing. Inside installation resulted in undesirable increases in daytime greenhouse temperatures when evaporative coolers were off. However, the heat gain associated with inside installation could be used to reduce heating costs during winter.

Light quality produced by shading with luminous white fiberglass and Saran shade cloth is comparable in the visible portion of the spectrum and is adequate for plant growth. Light transmitted by Saran shade cloth, when the shade is less than 75 percent of the available light, has been found to be comparable in quality to that under trees (Gaskin 1965).

Synthetic fabric shade cloths offer more advantages as a shade material for a research greenhouse, especially in areas of high solar insolation such as the southwestern United States, than fiberglass panels,

whitewash, or other materials such as lath. They offer ease of installation and removal, are relatively maintenance-free, and are available in a variety of densities for regulating light intensity and controlling temperature.

Literature Cited

Canham, A. E.

1964. Automatic glasshouse shading. *Solar Energy* 8(1):9-11.

Ekblad, Robert.

1973. Greenhouses: A survey of design and equipment. ED&T 2340. Growing seedlings in a controlled environment. Project Record. U.S. For. Serv. Equip. Dev. Cent., Missoula, Mont. 70 p.

Gaskin, T. A.

1965. Light quality under Saran shade cloth. *Agron J.* 57:313-314.

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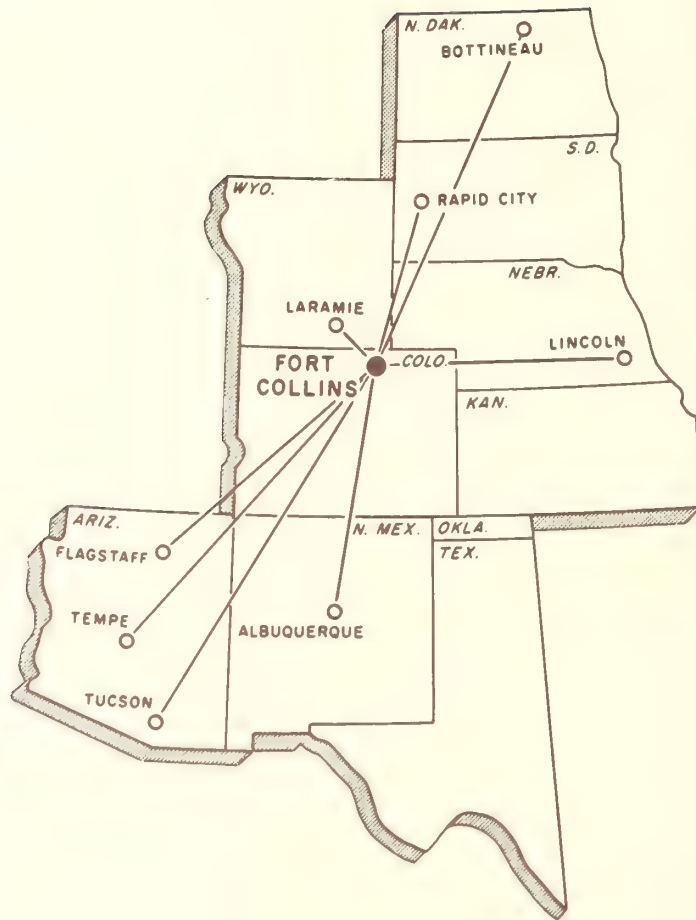
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How To Tell Engelmann From Blue Spruce in the Southwest



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BLUE SPRUCE—left, bark of mature tree; center, overmature tree; right, overmature tree with ridgy bark and epicormic twigs.

ENGELMANN SPRUCE— bark of mature (left) and overmature trees.



How To Tell Engelmann From Blue Spruce in the Southwest

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Abstract

The genetic and ecological distinctness of Southwestern spruces, and the importance of correct identification, are reviewed briefly. Photos show how to distinguish them by crown shape, branch angle, bark and foliage. (Either species may be blue.) The criteria are suited to quick on-the-job use by compartment examiners and timber markers. After brief use in the field, the characters become mental pictures and the guide is no longer needed.

About the covers:

Front: *A group of young mixed conifers, with a blue-colored Engelmann spruce on the left and a green-colored blue spruce on the right.*

Inside: *Differences in the bark of older trees are shown on the inside front cover. Differences in the bark of younger trees are shown on the inside back cover.*

Back: *Differences in branching and in foliage color of young spruce.*

How to Tell Engelmann From Blue Spruce in the Southwest

Engelmann spruce³ and blue spruce are often found together in Southwestern mixed conifer stands. While some foresters and biologists tell them apart readily and reliably, many cannot since either species may be blue. Recognizing these spruces is particularly a problem for people who are new to forests where the two occur together, but many old hands have trouble too.

The problem is more than academic. Engelmann spruce (ESp) and blue spruce (BSp) differ ecologically in some important respects. So far as summer temperatures are concerned, they occur together only in the warmer third of the ESp habitat spectrum, which is the cooler half of the BSp spectrum. BSp is better adapted to drought and high temperatures, and its seedlings survive full exposure to sunlight better than ESp seedlings. BSp has become an important windbreak species on the northern plains. ESp dominates large areas at elevations well above any occurrences of BSp, and is more shade tolerant. Such differences make species recognition important in selecting trees to be left for seed in the selection and shelterwood systems, and especially for seed collection. At least one seed lot supposedly collected from ESp trees has produced seedlings that turned out to be BSp (Jones 1975). An unknown number of these BSp have been planted on high-elevation ESp sites in New Mexico where they are not likely to survive.

Forest managers have asked for a guide to quick, reliable field identification. That is the objective of this paper.

Older Guides

As Daubenmire (1972) pointed out, existing taxonomic manuals are not very useful in telling these spruces apart. These trees overlap in certain morphological characteristics, which probably accounts for reports of hybrids in nature, as by Weber (1953) and

Porter (1957), and even of "fairly extensive natural crossing" cited by Alexander (1958). A recent mass collection, chromatography, and westwide hybrid indexes suggest that, while hybrids between ESp and BSp probably do occur in nature, they are rare (Daubenmire 1972, Taylor et al. 1975). Limited efforts to cross them artificially resulted almost entirely in empty or nonviable seeds, and the few seeds that germinated produced defective seedlings (Fechner and Clark 1969). Barriers to crossing included inhibition of pollen germination, premature death of pollen tubes, failure of the female gametophyte to develop following pollination, and failure of embryos to mature in cases where the egg was successfully fertilized (Kossuth and Fechner 1973).

Taxonomic manuals for the Southwest separate the two species almost entirely by the smoothness or pubescence of twigs, cone length, the persistence of old cones, and needle sharpness (Harrington 1954, Kearney and Peebles 1960, Martin et al. 1971, McDougall 1973). ESp twigs are said to be pubescent and BSp twigs hairless. But Daubenmire (1972) found that a substantial proportion of BSp had sparsely haired twigs and some had twigs on which hair was copious. Twigs on most ESp had copious hair, but on many, hair was sparse, and some had none. More important, these criteria, while somewhat useful, are not very practical on jobs such as compartment examination and timber marking.

Harrington (1954) also mentioned that, in Colorado, mature BSp have furrowed bark. In the Southwest, old BSp often have furrowed bark, but many mature BSp do not. In an article in *Colorado Outdoors*, Fechner (1973) pointed out that the immature cones of BSp are yellow green while those of ESp are blood red.

Recently, Daubenmire (1972) found that the two species can be reliably identified using characteristics of extracted cone scales. His method is useful only for cone-bearing trees, however, and does not fill the need for quick field identification because scales must be removed undamaged from the cones. Dry cones need to be soaked, or their scales will shatter when they are extracted.

³Common and scientific names of plants mentioned are listed on page 10.

The Approach Here

Several foresters and biologists confronted with this identification problem have asked for field coaching. They were pleased to find that, when certain characters were pointed out to them in the field, they could tell the two spruces apart easily, quickly, and confidently. The characters usually can be evaluated at a glance, but are not effectively described in words. Therefore, photographs are used here as a substitute for field coaching.

First we show characters of mature trees that are useful at a considerable distance. Next are characters that are useful at a few yards. Characters that require close examination are given last. For mature trees the latter are seldom needed.

While most of the characters used here are variable within each species, overlap between the two species is limited. Where appropriate, the variation within each species has been photographed. While sometimes a character taken singly will leave you in doubt, two or more taken jointly provide confident identification.

Unfortunately we do not know how to differentiate very young spruce seedlings after the hypocotyl of BSp germinants has lost its distinctive reddish color. When they are 5 to 10 years old—usually 6 inches tall or taller—they can often be identified, at least tentatively, and 3-foot seedlings usually can be identified with confidence.

Some characters of ESp vary with elevation. In this paper we are interested only in how ESp looks at elevations where BSp also grows—elevations below about 10,000 feet in the Southwest. Those are the ESp illustrated and described here. In the Southwest you are unlikely to see BSp as high as 10,000 feet, and ESp will rarely be seen as low as 8,000 feet.

Finally, this guide is based primarily on 15 years of observations in the White Mountains of Arizona, where the pictures were taken. Limited experience in other areas suggests that it is generally valid for Arizona, New Mexico, and southern Colorado, but that farther north it is less accurate. The characters listed here are unreliable for spruce planted and irrigated where they are not native.

What to Look For

At a Distance

At a distance the general outline of a BSp crown is usually different from that of an ESp. Mature trees can often be identified at 100 yards if their tops can be seen clearly.

Mature BSp crowns are often very narrow and typically retain a pointed top into old age (fig. 1). In old spruce a narrow pointed top is an almost positive



Figure 1.—Blue spruce crowns.





In 1B, the prominent crown to the right of the two blue spruces is a Douglas-fir.



indication that it is BSp. Also, individual branches of BSp usually appear more distinct and conspicuous than branches of ESp (fig. 2). Blue spruce branches commonly stick almost straight out. This is less apparent than usual in figure 1 because the upper crowns of 1A and 1E are heavily loaded with ripening cones and hang down somewhat. The lower crowns of those two trees, especially 1E, show the more usual branching character.

The right-hand crown in 1B is Douglas-fir.

Figure 2 shows a wide range of mature ESp crown forms. All the major crowns are ESp in each picture except 2D, where crowns of several species are outlined. The prominent central crown in 2D is a middle-aged ESp.

The rather open ESp crowns in 2F are not usual in the Southwest as a whole. They are more typical of ESp in the Chiricahua and Graham Mountains where there is no BSp.

At Close Range

Up closer, clumps of epicormic twigs sprout from the trunks of many BSp (inside front cover); and sometimes are very abundant. These epicormic twigs are typically 2 to 12 inches long. They often can be seen at a distance as a bushiness on the trunk (right-hand tree in fig. 1F).

Bark differences are probably the surest and simplest way to tell these spruces apart (inside front cover). The scales of old BSp bark look hard and tend to be oriented in vertical rows or ridges. In younger, mature BSp the scales look softer but still tend to form vertical rows. Bark of mature BSp is brown, gray-brown, or gray.

On mature and overmature ESp the bark scales appear larger, looser, and much more randomly arranged. Where scales have fallen from ESp bark, the underbark is commonly purplish but may also be reddish brown. The scales themselves are gray.



Figure 2.—Engelmann spruce crowns.





In 2D, the only prominent Engelmann spruce is the center tree.



Saplings are usually easy to identify at a little distance. The branches of BSp saplings are stiff and nearly at right angles to the trunk, tending to form separate planes at the nodes. The overall impression is of bristliness (fig. 3). In fact, BSp in general gives a sense of bristliness. The branches of ESp at these elevations look less stiff, rarely form planes, and give a softer appearance (fig. 4). Usually they angle upward from the trunk and commonly droop at the ends. Figure 5 shows two ESp saplings on the left, their branching contrasting sharply with the strongly planar branching of the three BSp at center and right.

Foliage color is often useful, especially in saplings and large seedlings. At elevations where both spruces grow, the foliage of young ESp is always at least

somewhat bluish and often quite blue. But while many BSp saplings are distinctly blue colored and some are intensely bluish white, ironically many other young BSp have no bluish tinge at all. In some locales the no-blue form of BSp predominates strongly; in others the blue form may be common. If a young spruce in a mixed conifer stand is green with a brassy tinge and **has no trace of blue**, it is BSp. If it is bluish it may be either species. On the outside back cover are two blue-colored ESp (left foreground). To the right of them is one blue-colored BSp between two green-colored BSp.

Many white fir in the Southwest also have distinctly blue-white foliage, and in a moment of carelessness can be mistaken for BSp.



Figure 3.—Young blue spruce, showing bristly planar branching.



Figure 4.—Young Engelmann spruce.



Figure 5.—A group of mixed spruces. The three at center and right, with planar branching, are blue spruce. The two on the left are Engelmann spruce.



Figure 6.—Sapling twigs of Engelmann spruce (left) and blue spruce (right).



Figure 7.—Closer view of blue spruce (left) and Engelmann spruce twigs.

Up Close

Close up, the bark of saplings and small poles is consistently different between the two species (inside rear cover). Bark of young BSp is more or less flaky looking, with reddish brown scales, even where stem diameter is smaller than 2 inches. Bark on ESp of the same size is light gray and sometimes has a yellowish tinge. It may be nearly smooth or have tight fine-textured scales. These inside cover pictures also point up again the comparatively bristly look of BSp.

The twigs and foliage of the two spruces also differ close up (figs. 6 and 7). Once again the bristly look of BSp is apparent, while ESp looks softer. ESp needles lie closer to the twigs in most cases, rather than nearly at right angles as with BSp. This is the main criterion in identifying smaller seedlings (figs. 8, 9, and 10).

Twig color is sometimes suggested as a criterion for identifying saplings and large seedlings, but it

can mislead you. In either species it may be gray, tan, or yellow. BSp twigs are often orange, and in almost all cases if the twigs are orange it is BSp. But very infrequently ESp have orange twigs.

In late spring when BSp buds are just opening, associated ESp have already made considerable new shoot growth.

The aroma of needles crushed between the fingers differs between the two species, at least for some people. The difference is hard to describe. Try it and see if it works for you.

When an individual character is ambiguous, looking at several should be decisive. It is our experience that, if an individual character clearly indicates BSp, or ESp, other characters will very rarely contradict it.

As you use this guide you will run into an occasional "if" or "but" not mentioned here. We left them out purposely. They are minor, and to go into them would obscure the pointers given here without helping spruce identification. You will discover the ifs and buts for yourself and find they are no problem.



Figure 8.—Engelmann spruce seedling.



Figure 9.—Blue spruce seedling.



Figure 10.—Seedlings of blue (left) and Engelmann spruce side by side.

Literature Cited

- Alexander, Robert R.
1958. Silvical characteristics of Engelmann spruce. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 31, 20 p. Fort Collins, Colo.
- Daubenmire, R.
1972. On the relation between *Picea pungens* and *Picea engelmannii* in the Rocky Mountains. Can. J. Bot. 50:733-742.
- Fechner, Gilbert H.
1973. The blue spruce—a Colorado tree. Colo. Outdoors, Nov.-Dec. 22(6)38-42.
- Fechner, Gilbert H., and Roger W. Clark.
1969. Preliminary observations on hybridization of Rocky Mountain spruces. Proc. Comm. For. Tree Breeding Can. 11:237-247.
- Harrington, H. D.
1954. Manual of the plants of Colorado. 666 p. Sage Books, Denver, Colo.
- Jones, John R.
1975. A southwestern mixed conifer plantation—case history and observations. USDA For. Serv. Res. Pap. RM-148, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.
- Kearney, Thomas H., and Robert H. Peebles.
1960. Arizona flora. 1085 p. Univ. Calif. Press, Berkeley and Los Angeles.
- Kossuth, Susan V., and Gilbert H. Fechner.
1973. Incompatibility between *Picea pungens* Engelm. and *Picea engelmannii* Parry. For. Sci. 19:50-60.
- Martin, William C., Charles R. Hutchins, and Robert G. Woodmansee.
1971. A flora of the Sandia Mountains, New Mexico. 301 p. Sandia Press, Albuquerque, N.M.
- McDougall, W. B.
1973. Seed plants of northern Arizona. 594 p. Mus. North. Ariz., Flagstaff.
- Porter, C. L.
1957. The Gymnospermae of Wyoming. Rocky Mt. Herb. Leaflet. 28. [Cited by Daubenmire 1972.]
- Taylor, Ronald J., Susan Williams, and R. Daubenmire.
1975. Interspecific relationships and the question of introgression between *Picea engelmannii* and *Picea pungens*. Can. J. Bot. 53:2547-2555.
- Weber, W. A.
1953. Handbook of plants of the Colorado Front Range. Univ. Colo. Press, Boulder. [Cited by Daubenmire 1972.]

Common and Scientific Names of Plants Mentioned

Engelmann spruce	<i>Picea engelmannii</i> Parry
Blue spruce	<i>Picea pungens</i> Engelm.
Douglas-fir	<i>Pseudotsuga menziesii</i> var. <i>glauca</i> (Beissn.) Franco
White fir	<i>Abies concolor</i> (Gord. & Glend.) Lindl.

Jones, John R., and Nelson T. Bernard.

1977. How to tell Engelmann from blue spruce in the Southwest. USDA For. Serv. Gen. Tech. Rep. RM-34, 10 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

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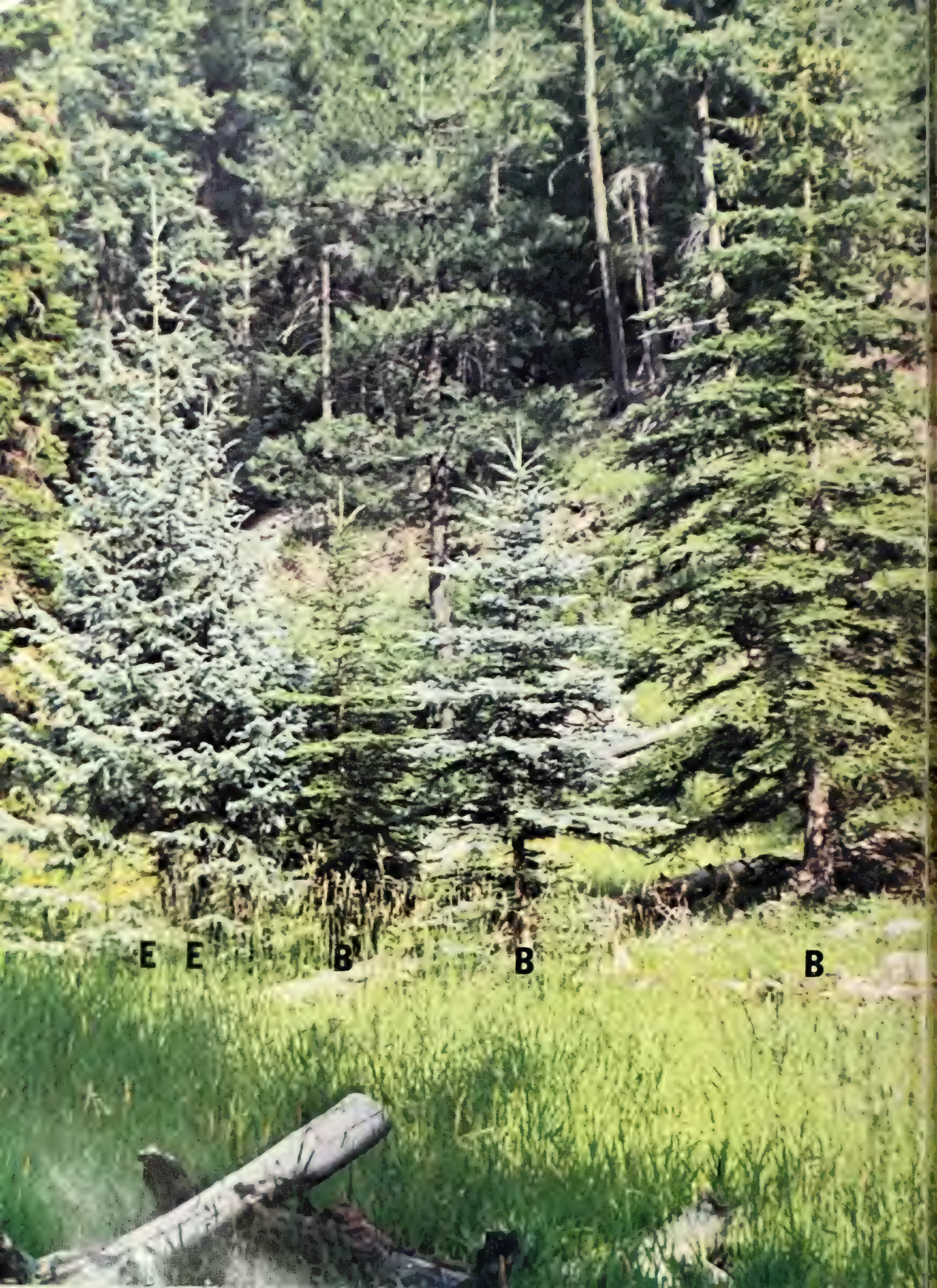
Keywords: *Picea engelmannii*, *Picea pungens*, field identification, taxonomy.



Bark of young blue spruce.

Bark of young Engelmann spruce.





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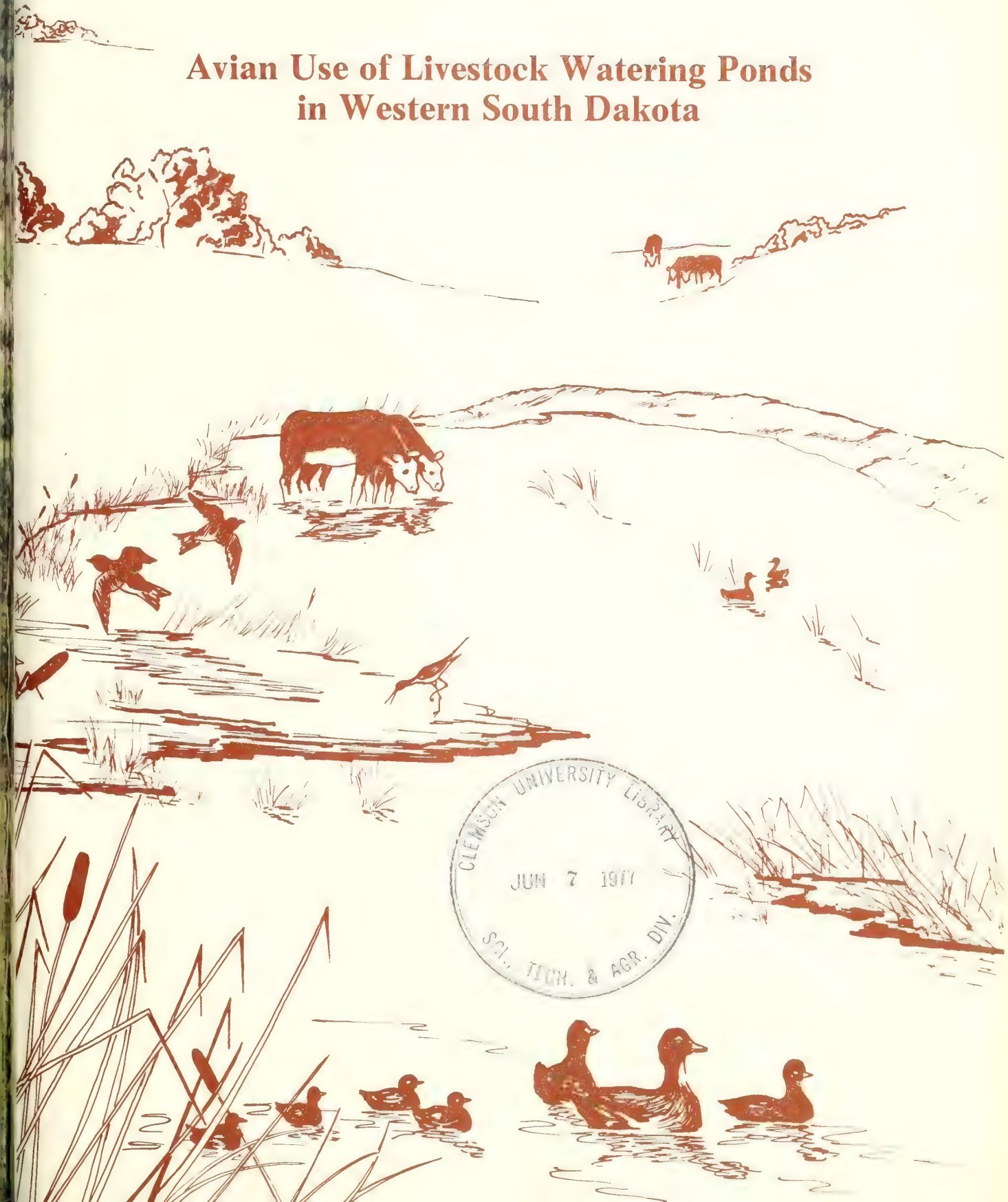
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Avian Use of Livestock Watering Ponds in Western South Dakota



Evans, Keith E., and Roger R. Kerbs.

1977. Avian use of livestock watering ponds in western South Dakota. USDA For. Serv. Gen. Tech. Rep. RM-35, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Waterfowl use from 1966 through 1972 peaked during the spring of 1967 when study ponds averaged 29 birds each. The average spring migration peak was 16.5 waterfowl per pond. Mallards and blue-winged teal made up 64 percent of adult waterfowl observed. Spring shorebird numbers peaked approximately 1 month later than waterfowl. The number of puddle duck young per pond during the peak of the brood season averaged 18, and varied from 10 to 24. Over the 7-year study period (1966-1972), 116 species of birds were observed in the area; 66 were upland birds not dependent on water developments. Large ponds (1-11 acres) in rolling topography with gently sloping shorelines, constant water levels, and abundant emergent and submerged vegetation, are best for duck brood production. An evaluation form for duck brood habitat was developed. Management implications and alternatives were discussed.

Keywords: Waterfowl use, duck brood production, wetland habitat.

Avian Use of Livestock Watering Ponds In Western South Dakota

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Avian Use of Livestock Watering Ponds in Western South Dakota

Keith E. Evans and Roger R. Kerbs

Background

Few natural ponds exist on the unglaciated portion of the northern Great Plains, but thousands of ponds have been dug in the area since the 1930's to provide water for livestock. Bue et al. (1964) estimated that 220,000 manmade watering ponds dot the landscape of South Dakota, North Dakota, eastern Montana, and western Minnesota. Before these stock ponds were constructed, upland areas near natural water were often overgrazed, and much of the remaining prairie was undergrazed. The livestock watering ponds have achieved two goals: better grazing distribution; and improvement and creation of wetland habitats, particularly suited for waterfowl and shorebirds.

Data in this report were collected from 1966 to 1972 during 113 visits to 12 western South Dakota study ponds. Information presented includes: (1) avian use of ponds; (2) a comparison of waterfowl brood use with pond characteristics; (3) a review of waterfowl food habits; and (4) management implications and alternatives based on data, observations, and literature review. Preliminary results were published in South Dakota Bird Notes (Evans and Kerbs 1967, 1972a). A checklist of birds of the Buffalo Gap

National Grasslands included some of these observations (Evans and Kerbs 1972b).

Kuchler (1964) showed the entire study area as a wheatgrass-needlegrass vegetation type. Although the region is classified as a mixed grass prairie, the vegetation in the waterways and drainage systems provides the diversity needed for many of the wildlife species found in the area. The topography of the study area generally is gently rolling (fig. 1) with some fairly steep areas (fig. 2). Some of the study ponds had mudflat shorelines.

The study ponds are located in Jackson County east of Wall, South Dakota. The South Fork Bad River is the main watershed for the area. The dominant land use practice is cattle grazing. Most ranchers in the area run a cow-calf operation.

Prior to 1969, the USDA Forest Service, Buffalo Gap National Grassland, managed the land under a summer-long grazing system. The area around most of the ponds was heavily grazed and dominated by blue grama (*Bouteloua gracilis*), buffalograss (*Buchloe dactyloides*), and bare soil. Beginning in 1969, the large pastures were cross-fenced into smaller units, and grazing was changed to a rest-rotation system under management by the Wall District, Nebraska National Forest, in cooperation with the White River Grazing Association.



Figure 1.—Study pond B in gently rolling area.



Figure 2.—Study pond J in area with fairly steep slopes.

Data Collection and Presentation

The study ponds were selected to represent gradients of pond characteristics such as size, depth, shoreline slope, vegetation abundance, and topography (table 1). A standardized route was established so each of the 12 ponds could be observed in 1 day. Observations were made every 2 weeks through the ice-free season of each year from 1966 through 1972. Caution was taken so as not to move birds from one pond to another during the count period. The 12 ponds were believed to be a representative sample of the ponds in the area.

Bird observations were recorded by date, study pond, species, and number of waterfowl and shorebirds. Killdeer² numbers were not recorded because they were abundant between ponds as well as near ponds, and not associated with a specific study pond. A nonquantitative checklist of upland birds for the study area was kept by species for each observation period.

²Common names of all birds are from AOU (1957), and 32nd Supplement (1972), thus eliminating the need for scientific names.

Vegetation characteristics were investigated in two phases: collection and identification of plant species in and around the 12 study ponds (Appendix); and establishment of photo points to document vegetation and physical changes during the study.

Migration

Waterfowl

Waterfowl use began immediately after the spring thaw, about the 15th of March (fig. 3).

Pintails, mallards, common mergansers, and green-winged teal were the first waterfowl to appear on the ponds. By April 1, many species were present. Use peaked during the April 1-15 period, with an average of nearly 17 waterfowl in each pond. The highest use occurred in 1967 when ponds averaged 29 birds each at the peak of spring migration. The years 1966 and 1970 were low-use springs, and in both years the migration peaked during the April 15-30 period. The study ponds seemed best suited for mallards and blue-winged teal; these two species made up 64 percent of the observations (table 2).

Table 1.—Description of study pond characteristics

Pond	Size ¹	Depth		Shoreline		Vegetation ³						Fish
		Max.	Ave.	Slope ²	Length	Shoreline		Emergent		Aquatic		
						1966	1972	1966	1972	1966	1972	
	<i>Acres</i>		<i>Feet</i>		<i>Feet</i>							
A	3.0	7.3	2.5	Flat	2,440	S	S	S	C	S	S	Bullhead
B	2.25	10.4	4.0	Steep	2,040	C	A	S	S	S	S	
C	2.25	5.0	2.0	Flat	2,920	S	A	S	A	C	A	
D	2.0	7.7	4.0	Inter- mediate	2,470	S	C	C	A	C	C	Bullhead, bass to 4 lbs.
E	11.0	8.0	4.0	Inter- mediate	5,590	C	C	C	C	S	C	Bullhead, blue- gill, bass to 4½ lbs.
F	10.0	7.0	3.0	Inter- mediate	4,660	A	C	C	C	C	C	Bullhead
G	7.0	7.5	2.5	Flat	2,720	S	C	S	C	C	A	Bullhead, bass to 2 lbs.
H	4.5	8.0	3.0	Inter- mediate	3,750	S	C	S	C	S	C	
I	7.0	8.0	3.0	Flat	4,340	S	C	S	C	C	C	
J	4.5	11.0	6.0	Steep	3,400	C	C	S	C	C	A	Bullhead
K	1.25	7.6	2.5	Inter- mediate	1,240	S	C	S	C	S	S	Bullhead
L	3.5	9.0	3.0	Inter- mediate	2,580	S	C	S	C	S	S	

¹Within ¼ acre at high water mark.

²Shoreline slope: 1:1 = steep; 1:3 = intermediate; 1:5 = flat.

³Vegetation: sparse (S); common (C); abundant (A).

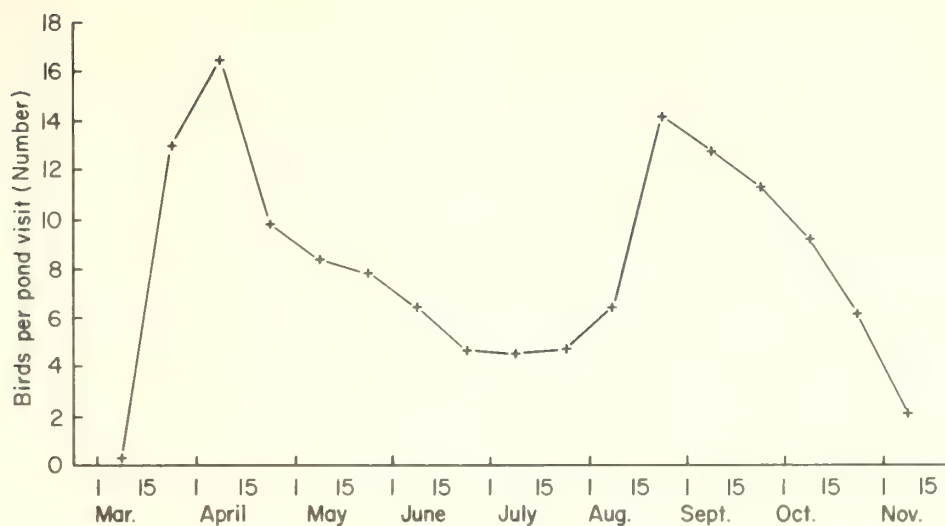


Figure 3.—Waterfowl migration patterns on western South Dakota stock watering ponds.

Table 2.—Relative frequency of the seven most common waterfowl (adults only) on the study ponds.

Species	Pond														Average
	B	J	K	H	A	L	C	D	G	E	I	F			
	Percent														
Mallard	56	54	36	40	41	42	45	42	40	38	34	28	41		
Blue-winged Teal	21	16	30	24	15	30	21	27	20	22	32	16	23		
Green-winged Teal	4	5	9	11	20	9	10	6	4	7	13	16	10		
Pintail	4	8	10	11	16	12	11	11	14	5	8	16	10		
Gadwall	13	8	10	8	4	3	10	11	8	13	5	8	8		
American Widgeon	2	8	4	3	3	2	2	1	12	13	7	13	6		
Shoveler	0	1	1	3	1	2	1	2	2	2	1	3	2		
Percent of total	2	4	4	5	5	5	10	11	12	13	13	16			

During the brood season, June 16-July 31, populations of adult waterfowl decreased to a low of five birds per pond visit. After August 1, many broods had attained adult size and plumage and were counted as adults. The fall migration peaked between August 15 and September 1. The average peak, which includes both young-of-the-year and adult migrants, reached 14 waterfowl per pond. Fall use was highest in 1967, nearly 30 ducks per pond.

Shorebirds and Other Waterbirds

Shorebirds were an important component of the avifauna on the study ponds. Spring migration peaked later for shorebirds (around May 15, fig. 4) than for waterfowl. Long-billed curlews were the first to appear, usually arriving in early April. Usually no more than 1 or 2 shorebirds were observed on all 12 study ponds during the April 1-15 period. By the May 1-15 observation period, shorebirds were commonly seen on all study ponds that had mudflat shorelines.

The most common shorebird associated directly with the ponds was the Wilson's phalarope. Phalarope nests were found within 50 feet of the shoreline, and phalaropes were observed feeding in shallow water throughout the summer.

Mergansers, coots, grebes, and cormorants were grouped together for analysis. Waterbird spring migration peaked between March 15 and April 1, and frequently included sizable numbers of common mergansers. The peak numbers in the fall were primarily coots and grebes (fig. 4).

Summary

Stock watering ponds were important in the spring and fall as feeding and resting areas for many species of birds. Peak numbers of waterfowl appeared on the ponds between April 1 and April 15, and August 15 and August 31. Shorebird spring migration peaked between May 15 and May 31; "fall" migration peaked between July 15 and July 31.

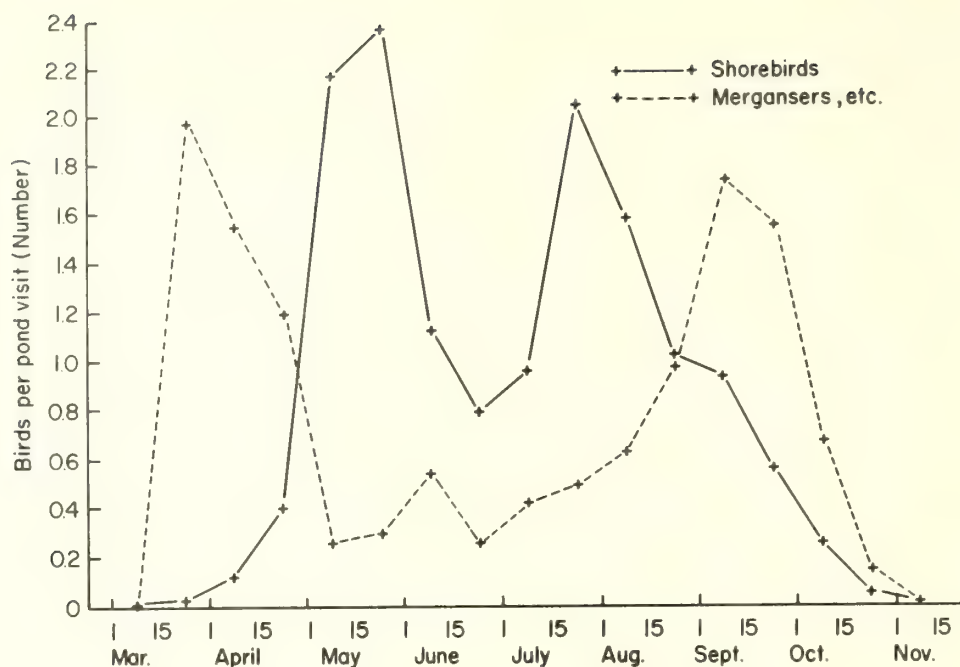


Figure 4.—Migration patterns of shorebirds and mergansers, coots, grebes, and cormorants, on stock watering ponds in western South Dakota.

Over the 7-year study period, 116 species of birds were observed in the vicinity of the study ponds. Sixty-six of these species were not counted but their occurrence was recorded (table 3). Most of these were upland birds that did not depend on water developments.

Production of Young

Waterfowl

Production of young waterfowl was based on the peak number of young observed on each pond during each year. Puddle duck production varied from a low of 10 young per pond in 1969 to a high of 24 in 1967 (table 4). The 7-year average (1966-72) was 18 young per pond. These production estimates are probably conservative, because early and late broods were not included in the count when peak numbers were observed.

Some broods were only observed on one occasion; it is not known whether they moved to another pond, or succumbed to unknown mortality factors. Bue et al. (1952) studied 50 stock ponds in Stanley County, South Dakota, during the summers of 1950 and 1951 and estimated an average of 22 young ducks produced per pond.

The 12 study ponds were quite variable in their value for brood production (table 4). They ranged

from an average of 1.9 young per year (less than 1 brood, pond A) to 37.4 young per year (over 5 broods per year, pond I).

Production also varied widely among the 7 study years. Numbers of broods, at the peak of the brood season, ranged from 26 in 1969 to 48 in 1971. Peak numbers of young waterfowl ranged from 119 in 1969 to 287 in 1967. Average brood size fluctuated between 4.6 and 6.5, with a 7-year average of 5.5. Brood numbers usually peaked during July, with an overall average of 3.2 broods per pond year. Lokemoen (1973) reported an average of 0.77 brood per pond in western North Dakota, while Rundquist (1973) reported an average of 4.9 broods per pond on grass-land areas in Montana.

Blue-winged teal produced almost half of the young ducks on the study ponds. Six species of puddle ducks produced the other half of the young:

Species	Percent of Total Young
Blue-winged teal	48
Mallard	26
Gadwall	11
Pintail	10
Shoveler	3
Green-winged teal	1
American widgeon	1

Table 3.—Other bird species observed in Jackson County, South Dakota

Species	Year						
	1966	1967	1968	1969	1970	1971	1972
Blackbird, Brewer's		X					X
Red-winged	X	X	X	X	X	X	X
Yellow-headed		X				X	
Bluebird, Mountain				X		X	
Bunting, Lark	X	X	X	X	X	X	X
Indigo							X
Catbird				X			
Chickadee, Black-capped					X		
Cowbird, Brown-headed	X	X	X	X	X	X	X
Crow, Common	X	X	X	X	X	X	X
Dove, Mourning	X	X	X	X	X	X	X
Rock		X				X	X
Eagle, Golden	X	X	X	X		X	X
Egret, Snowy					X		
Falcon, Prairie	X	X	X	X		X	X
Flicker, Common		X	X	X	X	X	X
Goldfinch, American					X		
Grackle, Common		X		X	X	X	X
Grouse, Sharp-tailed	X	X	X	X	X	X	X
Hawk, Ferruginous	X	X					
Marsh	X	X	X	X	X	X	X
Red-tailed	X	X	X	X	X	X	X
Rough-legged	X	X	X	X		X	X
Sharp-shinned		X					
Swainson's	X	X	X	X	X	X	X
Kestrel, American	X	X	X	X	X	X	X
Killdeer	X	X	X	X	X	X	X
Kingbird, Eastern	X	X	X	X	X	X	X
Western	X	X	X	X	X	X	X
Lark, Horned	X	X	X	X	X	X	X
Longspur, Chestnut-collared			X	X	X	X	X
McCown's		X					
Magpie, Black-billed	X	X	X	X	X	X	X
Meadowlark, Western	X	X	X	X	X	X	X

Species	Year						
	1966	1967	1968	1969	1970	1971	1972
Nighthawk, Common	X	X	X	X	X	X	X
Oriole, Northern					X		
Orchard		X		X	X	X	X
Owl, Burrowing	X						X
Great Horned		X	X	X	X	X	X
Short-eared							X
Phoebe, Say's							X
Pipit, Water							X
Sprague's							X
Pheasant, Ring-necked	X		X	X	X	X	X
Robin, American			X	X		X	X
Shrike, Loggerhead	X	X	X	X	X	X	X
Northern							X
Sparrow, Chipping							X
Grasshopper		X	X	X	X	X	X
House			X	X			
Lark		X		X	X	X	X
Savannah		X					
Tree							X
Vesper	X		X	X	X	X	X
White-crowned		X					X
Starling	X		X	X	X	X	X
Swallow, Barn		X	X	X	X	X	X
Cliff		X	X	X	X	X	X
Swan, Trumpeter							X
Thrasher, Brown	X	X	X	X	X	X	X
Towhee, Rufous-sided	X			X			
Vulture, Turkey	X	X	X	X			X
Warbler, Yellow						X	
Woodpecker, Hairy				X			
Redheaded							X
Wren, Rock				X			
Total species each year	29	40	34	42	38	46	46
Total species =	66						

Table 4.—Peak number of young waterfowl observed on each pond (number of broods in parentheses)

Pond	Year						
	1966	1967	1968	1969	1970	1971	1972
A	0(0)	0(0)	1(1)	0(0)	2(1)	3(1)	7(2)
B ¹	2(1)	9(2)	2(1)	22(3)	0(0)	4(1)	0(0)
J ²	6(1)	9(1)	22(4)	0(0)	7(1)	6(1)	0(0)
H ²	0(0)	0(0)	2(1)	5(1)	42(6)	7(2)	23(5)
L	14(2)	24(6)	14(3)	4(1)	18(3)	14(4)	6(1)
K ²	0(0)	44(8)	11(3)	10(2)	10(1)	34(8)	13(2)
E	47(7)	11(1)	18(5)	1(1)	13(2)	38(7)	20(5)
F	46(5)	18(3)	7(2)	19(5)	28(5)	20(3)	12(2)
G	13(4)	63(10)	21(4)	1(1)	7(1)	43(8)	19(3)
C	27(4)	17(2)	18(4)	31(6)	7(1)	41(8)	36(10)
D	40(6)	28(4)	53(7)	16(4)	30(6)	15(3)	14(3)
I	16(3)	64(7)	58(10)	10(2)	84(11)	6(2)	24(3)
Total	211(33)	287(44)	227(45)	119(26)	248(38)	231(48)	174(36)
Total	1497(270)						

¹Fenced in 1961.²Fenced in 1969.

Difference in behavioral patterns were observed between blue-winged teal and mallard broods. Blue-winged teal swam to the center of the pond when our presence was detected, while mallard broods headed for shoreline cover. Blue-winged teal tolerated other blue-winged teal broods on a pond; seldom was more than one mallard brood observed on one pond (fig. 5).

Data were not sufficient to correlate brood production with the highly variable vegetation conditions. Factors influencing vegetation characteristics included rapidly changing water levels and livestock grazing pressures. Livestock frequently entered most fenced enclosures.

Ponds A, B, H, and J had low duck production. Steep shorelines on B and J reduced the shallow water area and thus brood habitat. Shorelines on ponds A and H were heavily grazed at the start of the study, and waterfowl production was low. Pond H was not grazed in the springs of 1970 and 1972; vegetation cover and brood use increased in those years. Sparse aquatic vegetation and water level fluctuations that caused a large mud flat area on pond A made this pond better for shorebird use than for waterfowl nesting habitat.

The better producing habitat—ponds G, C, D, and I—were all between 2 and 7 acres, had flat to gently sloping shorelines, and common or abundant aquatic vegetation. The significance of these characteristics is discussed in the management alternatives section of this report.

Shorebirds and Other Waterbirds

Over the 7-year study period, 154 young upland sandpipers, long-billed curlews, Wilson's phalaropes, pied-billed grebes, and American coots were observed. Upland sandpipers, long-billed curlews, and killdeer were common and nested in the area on the uplands between ponds. These three shorebirds were grassland birds during the nesting season, and did not need specific habitat characteristics found around ponds. The pied-billed grebe and American coot preferred ponds with abundant aquatic and emergent vegetation.

Total Use

The 12 study ponds annually provided an average of 32,018 waterfowl days of use and 2,487 shorebird days of use (tables 5 and 6). Individual ponds had an average of 12 waterfowl using them during any visit during the summer. Adult waterfowl use of individual ponds was different from brood production. Total adult waterfowl use was higher on the larger ponds (7 to 11 acres). Bue et al. (1964) estimated that 200,000 waterfowl were produced annually on 20,320 stock ponds in South Dakota.

Figure 5.—Mallard and teal broods on a study pond.



Table 5.—Summary of waterfowl and shorebird use on 12 stock watering ponds in Jackson County, South Dakota

Year	No. visits	No. ice-free days	Shorebirds			Waterfowl		
			No. birds	Days use	Average no./pond visit	No. birds	Days use	Average no./pond visit
1966	15	214	122	1,741	0.7	1,740	24,824	9.7
1967	16	221	151	2,086	.8	3,010	41,576	15.7
1968	18	245	320	4,356	1.5	2,519	34,286	11.7
1969	17	227	169	2,257	.8	1,509	20,150	7.4
1970	16	220	149	2,049	.8	2,405	33,069	12.5
1971	16	219	155	2,122	.8	2,249	30,783	11.7
1972	15	233	180	2,796	1.0	2,539	39,439	14.1
Total	113	1,579	1,246	17,407	6.4	15,971	224,127	82.8
Av.	16	226	178	2,487	.9	2,282	32,018	11.8

Table 6.—Number of waterfowl and related species observed on 12 stock watering ponds in Jackson County, South Dakota

Species	Year							Total
	1966	1967	1968	1969	1970	1971	1972	
Bufflehead	4	3		4	11	1	6	29
Coot, American	12	118	79	15	17	118	60	419
Canvasback					13			13
Cormorant, Double-crested			2	1				3
Duck, Ring-necked		7	4	1	10	25	13	60
Ruddy	1	1	1		4	5	6	18
Gadwall	196	186	216	168	45	159	205	1,175
Goldeneye, Common				5				5
Goose, Canada				69	27	31	43	170
Grebe, Eared		1			3	8	2	14
Horned		1			1			2
Pied-billed	14	80	44	23	80	83	75	399
Western	1							1
Mallard	566	715	1,085	529	764	480	675	4,814
Merganser, Common	25	1	5	61	87	5	156	340
Hooded			1					1
Pintail	72	232	176	128	324	204	291	1,427
Redhead	4	42	1	26	57	23	198	351
Scaup, Lesser	19	15	13	25	25	24	57	178
Shoveler	34	20	28	15	15	56	29	197
Teal, Blue-winged	539	953	693	303	440	636	350	3,914
Green-winged	25	313	75	99	277	120	154	1,063
Widgeon, American	23	91	49	13	199	255	141	771
Unidentified Ducks	205	231	47	24	6	16	78	607
Total	1,740	3,010	2,519	1,509	2,405	2,249	2,539	15,971

Habitat Changes and Pond Succession

Grazing use by cattle had considerable effect on the vegetation in and around the study ponds over the study period. When the study began, the ponds were subjected to grazing throughout the summer (approximately 6 months). By 1969, the pastures containing the study ponds were managed by a deferred or rest-rotation grazing system. These systems periodically allowed the pond shorelines to be "rested" from grazing. Vegetation responded quickly to these rest periods (see table 1).

Two ponds not included in the 12 study ponds were built in early fall of 1969 and were full of water by mid-November. They were constructed in dry ravines dominated with western wheatgrass, blue grama, and contained some prairie rose (*Rosa woodsii*) and western snowberry (*Symphoricarpos occidentalis*). No pond-type vegetation was present before the dams were built, nor could their seeds or plant parts have washed in. However, during the following August, these plants were observed: green algae, duckpotato arrowhead, European waterplantain, common cattail, Sago pondweed, and a mudplantain

species. Plant succession progressed rapidly. By 1972 these ponds were well vegetated along the shoreline with some emergent and submersed vegetation. Additional species present in the fall of 1972 included: American pondweed, Duckweed mudplantain, creeping spikeweed, slender spikeweed, willow spp., plains poplar, common barnyardgrass, and narrow-leaved waterplantain. Several of these species are important food and cover plants for waterfowl (table 7).

Gleason and Cronquist (1964) suggested that seeds cling to the feathers, bill, and feet of waterfowl and shorebirds. DeVlaming and Proctor (1968) studied seed viability of 23 aquatic or semiaquatic plants after passage through the intestinal tract of killdeer and mallards, however, and concluded that internal conveyance seems more probable than wind dispersion or transport on the external surface of birds. Possibly both external and internal transport account for the rapid succession on these ponds.

One blue-winged teal and three mallards first used these newly constructed ponds on May 26, 1970. The following year, use increased to 26 ducks on the 2 ponds. One young Gadwall was seen on July 30, 1971. In 1972, use increased to 104 waterfowl, including 3 broods containing 14 young, during 15 visits to the 2 ponds.

Management Alternatives

Pond Location

Best waterfowl ponds are located in areas of rolling topography and constructed to provide a shoreline slope of less than 20 percent. Ponds for brood production should be more than 1 acre with adequate watershed area to maintain permanent water. Fill for the dam should be taken from a rather small area to create a deep pool in front of the dam that will remain relatively free from emergent and aquatic vegetation for many years and hold water longer. The watershed should be well vegetated and maintained so runoff water is relatively free from sediment.

This and other studies indicate the importance of a variety of pond characteristics to provide needed habitat components for a variety of waterfowl and shorebirds. Examples of preferences include: shorebirds use mudflats; waterfowl broods prefer shallow water with aquatic and emergent vegetation; waterfowl in general prefer larger ponds (1 to 10 acres). Ideally, several ponds of varying size, depth, and shoreline condition should be constructed in an area.

Breeding Habitat

Abundant emergent vegetation in shallow water is needed for brood habitat. This condition develops

naturally on ponds with gently sloping shorelines subjected to light grazing. Ponds do not need to be fenced to enhance waterfowl habitat under current rest-rotation grazing systems. The three study ponds categorized as having common emergent vegetation in 1966 produced more young than the other nine study ponds, which were categorized as having sparse emergent vegetation. Brood observations on pond B (steep shoreline, sparse emergent vegetation) were generally less than on other ponds. Aquatic vegetation seemed important to broods, but factors such as shoreline slope obscured any clearcut relationships.

One factor which warrants additional research is brood food. Bent (1951) listed general food habits of adult waterfowl, but said very little about young puddle ducks. Submerged aquatic vegetation plays an important role in providing habitat for many forms of invertebrates, which in turn are utilized as food by young waterfowl.

Waterfowl broods will travel a considerable distance overland to utilize a more favorable pond. Berg (1956) recorded brood movements from 0.38 to 1.02 miles, with an average movement of 0.71 mile.

Bue et al. (1952) concluded that female waterfowl selected the tallest, densest cover available. The broods in his study used ponds with grassy shorelines three to four times more than ponds with mudflat shorelines. Hamor et al. (1968) reported that good duck brood habitat contains about half open water and half emergent vegetation.

As an alternative to fencing, a rest-rotation grazing system utilizing already fenced pastures would undoubtedly be a less costly means of encouraging waterfowl production. Gjersing (1971) found both breeding pairs and broods increased in habitat given periodic relief from grazing. In our study, the vegetation in and around ponds became more lush, and appeared to be better for waterfowl production after rest-rotation grazing systems were implemented. Our vegetation analyses were insufficient to quantify rapid changes in cover and thus relate to brood production. On pond H, however, 82 percent of the broods counted in the 7-year study were produced during the 2 years the pond was protected from spring grazing.

Observations from this and other studies were used to develop a form to evaluate ponds with various sizes, shapes, and other characteristics for providing habitat for the production of waterfowl (inside back cover). This form can be used as a checklist in planning waterfowl habitat improvement projects, and for evaluating existing pond potential or past management programs. In aggregate, these individual component ratings indicate the potential value of a pond for providing duck brood habitat. Separately, they indicate habitat components that are lacking or inadequate and need improving.

Table 7.—Important food and cover plants for waterfowl on the Buffalo Gap National Grasslands (adapted from Martin et al. 1951, Muenscher 1944, and Fassett 1957).

Plant	Value as food or cover	Food parts consumed	Identification	Propagation	Habitat requirement
Sago pondweed or Fennelleaf pondweed	Excellent food, most important single waterfowl food plant.	Rootstalks, seeds, tubers.	Fanlike spreading of narrow leaves near water surface.	Regeneration from rootstalks, seeds and tubers.	Sandy mud, 2½-5 ft water, fresh water, can tolerate about 20 percent salinity.
Floatingleaf pondweed	Fair to good food.	Seed.	Numerous oval floating leaves, submerged leaves have bladeless leaf stalk.	Seed, rootstalks.	Fresh-water ponds and lakes at moderate depths, soft rich soils, acidity tolerance high.
Slender naiad	Excellent food.	Leafy parts, seed.	Narrow delicate serrate leaves with broad sheathing bases, awl-shaped seed, axial.	Transplant growing parts and seed.	Sandy bottoms in fresh water, pond margins.
Knotweeds, smartweed, fleeceflowers, cornbing	Good to excellent food.	Seed.	Semisubmerged, oval spikes of pink flowers.	Rootstalks, and seeds.	Fresh moderately acid or mildly alkaline water.
Bulrushes	Good cover, good to excellent food.	Seed.	Round-stemmed or leafy 3-angled forms.	Rootstalks, some by tubers.	Fresh to mildly brackish water, usually found in marshes, mud flats, or shallow water along shorelines.
Spikesedge	Good cover, good food.	Seed.	Round-stemmed, 1 to 28 inches tall.	Seed and rootstalks.	Marshes or moist places.
Cattail	Good cover, food.	Seed and rootstalks.	Long narrow leaves, club-like heads.	Seed and rootstalks.	Almost any wet place.
Muskgrass, stonewort	Good to excellent food.	All parts.	Tiny branches in whorls, musky odor, high in calcium, brittle.	Transplant.	Diverse habitats, real soil not required, alkaline or saline habitat preferred.
Watercress	Excellent food, some cover.	Seed and some parts of plant.	Divided leaves, small white flowers, seeds in pods, fleshy plant.	Seed and transplant cuttings.	Moist area, some require cool moving water.
Duckpotato	Fair food.	Tubers, seed.	White flowers in whorls of 3, arrow shaped leaves.	Seed and tubers.	Marshes, mud flats, shorelines, fresh to mildly brackish water.
Watercrowfoot or buttercup.	Indirectly very important as food value.	Harbors aquatic insects on which young waterfowl feed.	Submerged in water, some submerged leaves finely dissected, white-petaled flowers, sometimes yellowish at base.	Seed.	Aquatic, submerged, ponds, lakes.
Watermilfoil or parrotfeather	Indirectly very important, fair food.	Seed and vegetative parts harbor aquatic insects on which young waterfowl feed.	Dissected, compound leaves, flowers on emerged floating spikes.	Seed and transfer cuttings.	Aquatic, submerged, cool ponds.
Coontail	Indirectly very important, fair food.	Seed and vegetative parts harbor aquatic insects on which young waterfowl feed.	Freely branched submerged stems, leaves in whorls, dissected with minute teeth, rootless.	Seed and transfer cuttings.	Aquatic, submerged, quiet ponds, muck, rich soils and water on pond bottoms.

Habitat for Migrating Waterfowl and Shorebirds

Migrating waterfowl preferred the large ponds. Study ponds E and F—11 and 10 acres, respectively—were used extensively by migrating waterfowl, including the divers. Willow and cottonwoods were beginning to dominate the shorelines of many of the fenced ponds by the end of the study. If this trend continues, the ring of woody plants around ponds may decrease their value to migrating species that prefer good visibility.

Shorebirds seek mudflats and water less than 6 inches deep during migration. In the past, late fall and early spring grazing have created these conditions for the spring migration period. These conditions exist for the fall migration around ponds that receive heavy summer livestock use. Because shorebird and waterfowl brood habitat are not always compatible, we suggest grazing management systems that encourage mudflats on smaller ponds; and lush shorelines, emergents, and aquatic vegetation in and around some of the large ponds (over 1 acre).

Literature Cited

- American Ornithologists' Union.
1957. Check-list of North American birds. 5th Ed. 691 p. Lord Baltimore Press, Inc., Baltimore, Md.
- American Ornithologists' Union.
1973. Thirty-second supplement to the American Ornithologists' Union checklist of North American Birds. *Auk* 90:411-419.
- Bent, Arthur Cleveland.
1951. Life histories of North American wild fowl (order Anseres). Vol. 1, 244 p. Dover Publ. Inc., N.Y.
- Berg, P. F.
1956. A study of waterfowl broods in eastern Montana with special reference to movements and the relationship of reservoir fencing to production. *J. Wildl. Manage.* 20(3):253-262.
- Bue, I. G., L. Blankenship, and W. H. Marshall.
1951. The relationship of grazing practices to waterfowl breeding populations and production on stock ponds in western South Dakota. *Trans. N. Am. Wildl. Conf.* 17:396-414.
- Bue, I. G., H. G. Uhlig, and J. D. Smith.
1964. Stock ponds and dugouts. *In* Waterfowl tomorrow. Linduska, J. P. (Ed.), U.S. Dep. Inter., Wash., D.C. p. 391-398.
- DeVlaming, V., and V. W. Proctor.
1968. Dispersal of aquatic organisms: Viability of seeds recovered from the droppings of captive killdeer and mallard ducks. *Am. J. Bot.* 55:20-26.
- Evans, Keith E., and Roger R. Kerbs.
1967. Waterfowl and shorebirds use on selected stock ponds in Jackson County: 1966. *S.D. Bird Notes* 19(2):28-30.
- Evans, Keith E., and Roger R. Kerbs.
1972a. Some birds of Jackson County, South Dakota. *S.D. Bird Notes* 24(4):76-77, 81. (Whole No. 95).
- Evans, K. E., and R. R. Kerbs.
1972b. Birds of the Buffalo Gap National Grassland. (Checklist) U.S. Dep. Agric., For. Serv., Reg. 2, Denver, Colo.
- Fassett, Norman C.
1957. A manual of aquatic plants. 405 p. Univ. Wis. Press, Madison.
- Gjersing, F. M.
1971. A study of waterfowl production on two rest-rotation grazing units in north central Montana. M.S. thesis. Mont. State Univ., Bozeman, 42 p.
- Gleason, H. A., and A. Cronquist.
1964. The natural geography of plants. 420 p. Columbia Univ. Press, N.Y.
- Hamor, W. H., H. G. Uhlig, and L. V. Compton.
1968. Ponds and marshes for wild ducks on farms and ranches in the northern Plains. U.S. Dep. Agric., Farmers' Bull. 2234, 16 p.
- Kuchler, A. W.
1964. Potential natural vegetation of the conterminous United States. *Spec. Publ.* 36, 116 p. Am. Geogr. Soc., N.Y.
- Lokemoen, John T.
1973. Waterfowl production on stock-watering ponds in the northern Plains. *J. Range Manage.* 26:179-184.
- Martin, Alexander C., Herbert S. Zim, and Arnold L. Nelson.
1951. American wildlife and plants. 500 p. Dover Publ., Inc., N.Y.
- Muenschner, Walter Conrad.
1944. Aquatic plants of the United States. 374 p. Cornell Univ. Press, Ithaca, N.Y.
- Rundquist, V. M.
1973. Avian ecology on stock ponds in two vegetational types in north-central Montana. Pittman-Robertson Completion Rep. W-120-R-1-5. Mont. Fish and Game Dep., Helena, 116 p.

Appendix

Plant Species Collected In and Near 12 Study Ponds in Jackson County, South Dakota

Scientific Name	Common Name		
<i>Alisma gramineum</i> Gmel.	Narrowleaved waterplantain	<i>Plagiobothrys scopulorum</i> (Greene) Johnst.	Popcornflower
<i>Alisma plantago-aquatica</i> L.	European waterplantain	<i>Polygonum coccineum</i> Muhl.	Swamp knotweed
<i>Ammania coccinea</i> Roth	Purple ammania	<i>Polygonum lapathifolium</i> var. <i>salicifolium</i> Sibth.	Curltop ladysthumb
<i>Bacopa rotundifolia</i> (Michx.) Wettst.	Disk waterhyssop	<i>Potamogeton diversifolium</i> Raf.	Waterthread pondweed
<i>Callitriche hermaphrodita</i> L.	Water-starwort	<i>Potamogeton nodosus</i> Poir.	American pondweed
<i>Carex brevior</i> (Dewey) Mack.	Sedge	<i>Potamogeton pectinatus</i> L.	Fennelleaf or Sago pondweed
<i>Ceratophyllum demersum</i> L.	Hornwort	<i>Potamogeton richardsonii</i> (Benn.) Rydb.	Richardson pondweed
<i>Chara</i> Vaill.	Stonewort	<i>Potamogeton zosteriformis</i> Fern.	Flatstem pondweed
<i>Echinodorus berteroi</i> (Spreng.) Fassett	Bur head	<i>Ranunculus aquatilis</i> L.	Watercrowfoot buttercup
<i>Elatine triandra</i> Schkuhr	Waterwort	<i>Ranunculus longirostris</i> Godr. (<i>R. circinathus</i> Sibth.)	Longbeak buttercup
<i>Eleocharis acicularis</i> R. & S.	Slender spikesedge	<i>Rorippa islandica</i> (Oed.) Borbas	Marshyellow watercress
<i>Eleocharis palustris</i> (L.) R. & S.	Creeping spikesedge	<i>Rorippa sinuata</i> (Nutt.) Hitchc.	Spreadingyellow watercress
<i>Heteranthera limosa</i> (SW.) Willd.	Ducksalad mudplantain	<i>Sagittaria cuneata</i> Sheld.	Duckpotato arrowhead
<i>Juncus interior</i> Wieg.	Inland rush	<i>Salix amygdaloides</i> Anderss.	Peachleaf willow
<i>Limosella aquatica</i> L.	Water mudwort	<i>Salix interior</i> Rowlee	Sandbar willow
<i>Marsilea mucronata</i> A.Br.	Common pepperwort	<i>Scirpus acutus</i> Muhl.	Tule bulrush
<i>Mirabilis linearis</i> (Pursh) Hiemerl.	Narrowleaf four-o'clock	<i>Scirpus validus</i> Vahl.	Softstem bulrush
<i>Myriophyllum exalbescens</i> Fern.	Parrotfeather	<i>Trifolium dubium</i> Sibth.	Suckling clover
<i>Najas flexilis</i> (Willd.) Rost. & Schmidt	Slender naiad		

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1977. Avian use of livestock watering ponds in western South Dakota. USDA For. Serv. Gen. Tech. Rep. RM-35, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Waterfowl use from 1966 through 1972 peaked during the spring of 1967 when study ponds averaged 29 birds each. The average spring migration peak was 16.5 waterfowl per pond. Mallards and blue-winged teal made up 64 percent of adult waterfowl observed. Spring shorebird numbers peaked approximately 1 month later than waterfowl. The number of puddle duck young per pond during the peak of the brood season averaged 18, and varied from 10 to 24. Over the 7-year study period (1966-1972), 116 species of birds were observed in the area; 66 were upland birds not dependent on water developments. Large ponds (1-11 acres) in rolling topography with gently sloping shorelines, constant water levels, and abundant emergent and submerged vegetation, are best for duck brood production. An evaluation form for duck brood habitat was developed. Management implications and alternatives are discussed.

Keywords: Waterfowl use, duck brood production, wetland habitat.

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HABITAT EVALUATION FORM

Habitat Component	Rating					
1. Size:						
A. Temporary water	Unsuitable	C. Spikerush	0	1	2	3
B. Permanent water, less than 1 surface acre	Inadequate	D. Bulrush	0	1	2	3
C. Permanent water, more than 1 surface acre	Good	E. Cattail	0	1	2	3
2. Average shoreline slope, measured from existing water level:		F. Naiad	0	1	2	3
A. More than 3 feet per 5 horizontal feet	Unsuitable	G. Buttercup	0	1	2	3
B. 2-3 feet per 5 horizontal feet	Poor	H. Watermilfoil	0	1	2	3
C. 1-2 feet per 5 horizontal feet	Fair	I. Coontail	0	1	2	3
D. 0-1 foot per 5 horizontal feet	Good	J. Stonewort	0	1	2	3
3. Shoreline vegetation within 10 feet of existing water level:		6. Emergent and aquatic vegetation (refer to ranking of plants in Item 5):				
A. 0-25 percent of the shoreline vegetation covered, or shoreline completely covered with tall rank vegetation with no open shoreline for brood resting sites	Unsuitable	A. No plant on list is ranked above the rare (1) category.			Unsuitable	
B. 25-50 percent vegetation covered	Poor	B. No plant listed in A through D is ranked as common, but sufficient emergent and aquatic vegetation exists to rank some of the 10 listed species above the rare category. Less than 25 percent of the area of water less than 2 feet deep is occupied by listed plant species.			Poor	
C. 50-75 percent vegetation covered	Fair	C. At least 1, and preferably 2, of the plants listed in A through D are common on the pond. Aquatic and emergent vegetation occupies 25-50 percent of the water area less than 2 feet deep.			Fair	
D. Over 75 percent vegetation covered, except as in A	Good	D. There is a good variety, at least 5 of the plants listed, of the aquatic and emergent plant species occupying over half of the water area less than 2 feet deep (except as in E). Two or more of the species listed in A through D are common on the pond.			Good	
4. Existing water conditions:		E. Pond is completely or nearly completely covered with emergent and aquatic vegetation (choked).			Unsuitable	
A. Water level low with shoreline vegetation either absent or excessively trampled by livestock	Poor					
B. Water level low with a good cover of shoreline vegetation, or pond approximately half full	Fair					
C. Pond full or nearly full	Good					
5. Food and cover plants (circle selected rank as follows: 0 = absent; 1 = rare; 2 = occasionally; and 3 = common):						
A. Pondweed	0 1 2 3					
B. Smartweed	0 1 2 3					

